Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/089

Newfoundland and Labrador, Quebec, Maritimes, and Central and Arctic Regions

An update on the biology, population status, distribution, and landings of wolffish (*Anarhichus denticulatus*, *A. minor*, and *A. lupus*) in the Canadian Atlantic and Arctic Oceans

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December 2013

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Simpson, M.R., Chabot, D., Hedges, K., Simon, J., Miri, C.M., and Mello, L.G.S. 2013. An update on the biology, population status, distribution, and landings of wolffish (*Anarhichus denticulatus*, *A. minor*, and *A. lupus*) in the Canadian Atlantic and Arctic Oceans. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/089. v + 82 p.

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ABSTRACT

This paper presents the most recent information on trends in abundance, distribution, and fishery removals of *Anarhichus denticulatus* (Northern Wolffish), *A. minor* (Spotted Wolffish), and *A. lupus* (Atlantic Wolffish) in the Northwest Atlantic and Arctic Oceans; and presents new biological research, in support of a 5-year review of progress made in achieving the objectives of the Recovery Strategy and Management Plan for these species. Previously, all three species were listed on Schedule 1 of Canada's *Species at Risk Act (SARA)* as being at risk, due to significant declines in relative abundance indices and reduction in area occupied during the 1980s and early 1990s. Their status was recently (November 2012) upheld by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Signs of population recovery have been detected in some, but not all, regions. For example, indices of relative abundance and distribution for some wolffish species tended to increase in a number of areas surveyed in the Newfoundland and Labrador (NL) Region during the last decade. In recent years, there was a very gradual increase in catch rates of Northern Wolffish during the Fisheries and Oceans Canada (DFO) spring research survey in Div. 3LNO, and during the fall survey in Div. 2J3K and Div. 3LNO. Additionally, in recent years, during the DFO fall research survey in Div. 2J3K and Div. 3LNO, catch rates of Spotted Wolffish were generally increasing. However, during the spring survey, following a general increase in Div. 3LNO over 1995-2006, catches of this species have been declining. In the Maritimes Region, annual mean number per tow for Atlantic Wolffish in the DFO research surveys has declined since 1990, while area of occupancy for this species has exhibited a persistent decline from approximately 60,000 km^2 in 1975, to about 10,000 km^2 in 2012.

Due to their status under *SARA*, mandatory release of Northern Wolffish and Spotted Wolffish is required of fishers operating in Canadian waters. Commercial fishing records of wolffish remain unspeciated, and do not report discards at-sea (except for Canadian Fisheries Observers' data). *Species at Risk Act* logbook data from fishers aboard > 35 foot commercial vessels fishing in Canada's exclusive economic zone (EEZ) indicated that a large percentage of wolffish were released alive in 2005-10, with apparent decreases in the percent alive for Northern Wolffish and Atlantic Wolffish since then.

In the Gulf of St. Lawrence (GSL), dissolved oxygen levels where some wolffish are found were shown to reduce growth rates of Spotted Wolffish in laboratory studies. Further research is required to determine the effects of reduced oxygen on survival, maturation, fertility, egg development, and hatching success of all three wolfish species.

Mise à jour concernant les caractéristiques biologiques, la situation des populations, la répartition et les débarquements de loups de mer (*Anarhichus denticulatus*, *A. minor* et *A. lupus*) dans les eaux canadiennes des océans Arctique et Atlantique

RÉSUMÉ

Ce document présente les renseignements les plus récents sur les tendances concernant l'abondance, l'aire de répartition et les prélèvements par la pêche du *Anarhichus denticulatus* (loup à tête large), du *A. minor* (loup tacheté) et du *A. lupus* (loup atlantique) dans l'océan Atlantique Nord-Ouest et l'océan Arctique. Il présente également de nouveaux résultats de recherche biologique à l'appui d'un examen quinquennal des progrès réalisés dans l'atteinte des objectifs du programme de rétablissement et du plan de gestion concernant ces espèces. Auparavant, ces trois espèces étaient inscrites à l'annexe 1 de la *Loi sur les espèces en péril* (LEP) du Canada comme espèces en péril en raison des diminutions importantes des indices d'abondance relatifs et des réductions de l'occupation des zones habitées dans les années 1980 et au début des années 1990. Leur situation a récemment été confirmée (novembre 2012) par le Comité sur la situation des espèces en péril au Canada (COSEPAC).

Des signes de rétablissement des populations ont été observés dans certaines régions, mais pas dans toutes. Par exemple, des indices d'abondance et d'aire de répartition relatifs pour certaines espèces de loup de mer avaient tendance à accroître dans un certain nombre de zones étudiées dans la région de Terre-Neuve-et-Labrador (T.-N.-L.) au cours de la dernière décennie. Au cours des dernières années, on a observé une augmentation graduelle des taux de prises de loups à tête large durant les relevés de recherche printaniers de Pêches et Océans Canada (MPO) dans la division 3LNO et durant les relevés d'automne dans les divisions 2J3K et 3LNO. De plus, au cours des dernières années, on a observé une augmentation générale des taux de prises de loups tachetés durant les relevés d'automne du MPO dans les divisions 2J3K et 3LNO. Ces taux de prises sont toutefois en baisse durant les relevés printaniers depuis une augmentation générale observée dans la division 3LNO entre 1995 et 2006. D'après les relevés de recherche du MPO effectués dans la région des Maritimes, le nombre moyen annuel de loups atlantiques par trait a diminué depuis 1990, tandis que la zone d'occupation (ZO) de ces espèces affiche une diminution persistante, passant d'environ 60 000 km^2 en 1975 à quelque 10 000 km^2 en 2012.

En raison de leur situation en vertu de la *LEP*, les pêcheurs dont les activités se trouvent dans les eaux canadiennes doivent obligatoirement remettre à l'eau le loup à tête large et le loup tacheté. Les registres de pêche commerciale du loup de mer demeurent non différenciés et ne déclarent pas les rejets en mer (à l'exception des données provenant des observateurs des pêches canadiennes). Les données du journal de bord de la *LEP* à bord de navires commerciaux mesurant plus de 35 pieds et pratiquant la pêche dans la zone économique exclusive (ZEE) du Canada indiquent que de 2005 à 2010, un pourcentage élevé de loups de mer avaient été remis à l'eau vivants, mais que le pourcentage de loups à tête large et de loups atlantiques remis à l'eau vivants semble avoir diminué depuis.

Par suite d'études en laboratoire, on a constaté que les niveaux d'oxygène dissous où se trouvent certains loups de mer dans le golfe du Saint-Laurent avaient une incidence sur les taux de croissance du loup tacheté. D'autres recherches doivent être menées pour déterminer les effets d'une teneur réduite en oxygène sur la survie, la maturation, la fertilité, le développement des œufs et le succès de l'éclosion pour ces trois espèces de loups de mer.

INTRODUCTION

Three wolffish species are found in both Canadian Atlantic and Arctic waters: *Anarhichas denticulatus* (Northern Wolffish), *A. minor* (Spotted Wolffish), and *A. lupus* (Atlantic Wolffish). The first two species were designated Threatened by COSEWIC under Canada's *SARA* in 2001; whereas Atlantic Wolffish was designated of Special Concern (Kulka et al. 2004a). The primary reasons for listing wolffish as species at risk include greater than 90% declines in abundance indices over 2-3 generations (1980s-90s), concurrent with substantial reductions in extent of distribution.

The Recovery Strategy for Northern Wolffish and Spotted Wolffish, and Management Plan for Atlantic Wolffish in Canada were published on the *SARA* public registry in February 2008. In September of 2010, a zonal pre-COSEWIC assessment of the three wolffish species was held to review the available data (Dutil et al. 2011; Simpson et al. 2011; Simon et al. 2012). In November of 2012, COSEWIC re-evaluated the status of wolffish in Atlantic Canada, and concluded that, despite signs of population recovery, Northern Wolffish and Spotted Wolffish remain listed as Threatened under *SARA*, while Atlantic Wolffish is still of Special Concern.

As part of the federal *SARA* process, DFO is required to provide a 5-year report and update on the implementation of the Recovery Strategy and Management Plan for wolffish (Kulka et al. 2007), and on the progress towards meeting recovery objectives. The general intent of this paper is to provide recent scientific information in support of a review of Northern Wolffish, Spotted Wolffish, and Atlantic Wolffish under Sections 46, 55, and 72 of Canada's *SARA*. As such, it updates the trends in research survey abundance and distribution indices, as well as fishery removals of these three species of wolffish, and provides new biological information, in support of the 5-year review.

MATERIALS AND METHODS

This research document is divided into three sections - one which provides an update of research survey abundance and distribution indices (where available) for the four regions; one which provides an update of commercial fisheries removals; and one which presents new biological information on hypoxia tolerance of Atlantic and Spotted Wolffish from studies conducted in the Gulf Region.

DISTRIBUTION AND ABUNDANCE

Central and Arctic Region

Surveys

Details of the DFO research vessel (RV) surveys in the Northwest Atlantic Fisheries Organization (NAFO) Subarea 0 are provided in Simpson et al. (2011). As of 2006, the survey expanded to include Div. 2G and Hudson Strait.

Survey Distribution and Abundance Indices

A point map of the geographic distribution of the three wolffish species was plotted using location of capture data from the DFO RV surveys.

Newfoundland and Labrador Region

Surveys

Data were obtained during multi-species bottom trawl surveys conducted throughout the continental shelves of Newfoundland and Labrador (NAFO Div. 2GHJ3KLMNO and Subdiv. 3Ps) in spring (1971-2012) and fall (1977-2011); including areas beyond the Canadian EEZ

(Table 1; Fig. 1). The surveys employed a stratified random design based on depth intervals and location (latitude and longitude), and were designed to provide information on abundance, distribution, and area occupied by several demersal and benthic fish and invertebrate species. A summary of the survey design employed in the NL Region can be found in Doubleday (1981). Simpson et al. (2011) provided a detailed description of the surveys in relation to wolffish. It should be noted that several demersal fishing gears have been deployed during the spring and fall surveys, and no conversion factors exist between the different gears for wolffish species; therefore, each time series should be considered independently. In addition, Subdiv. 3Ps was initially surveyed each winter until 1993, at which point it was surveyed annually in the spring.

Survey Distribution and Abundance Indices

Point maps of the geographic distribution of standardized catch rate (no. fish/tow) were plotted using data from the recent surveys. Prior year point pattern maps are published elsewhere (e.g., Kulka et al. 2004; Simpson et al. 2011). In addition, standardized catch rates were used to create kernel density surface plots for spring and fall Engel and Campelen surveys (seasons and years combined) for Northern, Spotted and Atlantic Wolffish using ArcGIS. Methodology for estimating abundance was described in Simpson et al. (2011).

Methodology for calculating area of occupancy using survey data was described in Simpson et al. (2011).

Gulf Region

Surveys

Details of the annual DFO groundfish bottom trawl surveys conducted by Gulf and Quebec regions, as well as the fixed and mobile gear sentinel fisheries surveys, are provided in Dutil et al. 2011. It is important to note that, for the northern GSL, different survey vessels and gear were used prior to 1990, and another vessel and gear change took place in 2004. For the latter, a conversion factor exists only for Atlantic Wolffish (Bourdages et al. 2007).

Survey Distribution and Abundance Indices

The distribution of the three species of wolffish in the northern (Div. 4RS) and southern (Div. 4T, excluding the GSL Estuary) GSL, as described by Dutil et al. (2011), has not been updated for the present document. It provides maps of the distribution of wolffish species in the GSL according to several survey types, including RV surveys.

In the northern GSL, the abundance of the three Wolffish species was assessed as mean mass per tow for each survey year, taking into account the stratification of the survey. Only the RV *Alfred Needler* (1990–2003) and CCGS *Teleost* (2004–12) series were considered. Some strata were missing in some years. Abundance in missing strata was estimated from the abundance in the same strata for the 3 previous years, so that survey coverage was consistent for the entire 1990-2012 period (Bourdages and Ouellet 2011). In the southern GSL, abundance of Atlantic Wolffish was assessed as average number per tow for each year of the survey, taking into account the stratification of the survey.

Dutil et al. (2011) calculated the relative occurrence for each Wolffish species and each year (the number of sets where the species was present divided by the total number of sets, the stratification scheme of the surveys was not taken into account) for the period 1978 to 2008, using a variety of surveys and gears. For this document, their measures of relative occurrence based on RV surveys (RV *Lady Hammond*, summer, 1984-89, RV *Gadus Atlantica*, winter, 1978–90) for the period 1978 to 1989 were reused.

For the period 1990 to 2012, the closely related area of occupancy index was calculated as described in Simpson et al. (2011), using data from RV *Alfred Needler* (1990–2003) and CCGS

Teleost (2004–12). Area of occupancy was expressed as a percent of the area surveyed each year, to compensate for small differences in survey coverage and to be compatible with the relative occurrence calculated by Dutil et al. (2011) for earlier years. In fact the area of occupancy, as calculated here, was almost identical to the relative occurrence for the years where both methods were used (1990 to 2008). Area of occupancy was calculated after excluding the Estuary, where wolffish were always absent from the catches, and Subdiv. 3Pn, which has not been sampled by the survey since 2003. Area of occupancy (relative occurrence) has not been updated for the southern GSL since Dutil et al. (2011).

Maritimes Region

Surveys

The DFO summer survey has been conducted annually on the Scotian Shelf (Div. 4VWX) since 1970 using a stratified random design based on depth and geographic area (Fig. 2). The February/March RV survey on Georges Bank (Subdiv. 5Ze) commenced in 1986 using Western IIA trawl gear and a stratified random design. Details of these surveys were provided in Simon et al. (2011).

A number of surveys were conducted in the waters inshore of the summer RV survey off Southwest Nova Scotia (SWNS) and the Bay of Fundy. These surveys were conducted in 1985-86 using the JL Hart, a 65' stern trawler using a rockhopper type of gear and the Labradelle, a 25' vessel that used a small shrimp trawl very near shore primarily looking for juvenile gadids. From 1991 to 1993, a series of surveys were conducted off SWNS by the JL Hart exploring the area for bottom that would for suitable for an inshore survey. These surveys were combined into one data set to determine the distribution of wolffish in this inshore area. Simon et al. (2011) had reported, anecdotally, that fishers had been concentrating fishing effort on 'Catfish Holes' that yielded very large Atlantic Wolffish in the area where these surveys were conducted. Length frequency information was summarized to examine this observation.

Additionally, four industry/science surveys, based in the Maritimes Region and conducted since the mid-1990s, were described and evaluated by Simon et al. (2011). They are: the Individual Transferable Quota (ITQ) Fixed Station Industry Survey in Div. 4X; the 4VsW Sentinel Survey; the Halibut Industry Survey in Div. 3MNOP4VWX, on the Scotian Shelf and southern Grand Bank; and the Snow Crab Industry survey in Div. 4VWX. These surveys were updated using the available data. In addition, the 4Vn Sentinel Survey, a stratified random longline survey conducted by industry participants, was examined for the presence of all three species of wolffish.

Survey Distribution and Abundance Indices

Methodology for estimating distribution, abundance and trends in population size were described in Simon et al. (2011). Methodology for calculating area of occupancy, for each of the surveys, was also described in Simon et al. (2011).

COMMERCIAL FISHERIES REMOVALS

Commercial fishery removals of three species of wolffish in NAFO Subareas 0-2, Div. 3KLNOP, Div. 4RST, Div. 4VWXY, and Div. 5Z were examined for 1960-2011, using commercial data available in several databases: the NAFO STATLANT-21A unspeciated wolffish catch data (1960-2012), reported by NAFO member countries fishing mainly outside Canada's 200-mile limit; DFO-NL Zonal Interchange Format (ZIF) unspeciated wolffish landings data (1985-2011), and DFO-MARFIS (Maritime Fishery Information System) unspeciated wolfish landings data (2002-11), reported by Canadian fishers operating in Canada's EEZ; and

Canadian Fisheries Observers' speciated catch and discards data (1978-2011), collected on a set-by-set basis on board commercial fishing vessels at sea.

With NAFO-reported data, total reported catches of unspeciated wolffish were calculated by year and Subarea/Division. With ZIF and MARFIS data, total reported landings of unspeciated wolffish were calculated by year, Subarea/Division, fishery type (i.e., bycatch or directed wolfish fisheries), and fishing gear type. With Fisheries Observer data, total catches and discards of each species of wolffish were analyzed by year and Subarea/Division. Observers' discard data were also prorated to ZIF total groundfish landings inside Canada's 200-mile limit to estimate annual wolffish discards in Canada's EEZ. This was done by multiplying the total observed wolffish discards (per species) and ZIF total reported landings of all groundfish species, then dividing this estimate by the total observed catch of all groundfish species. Observers also collected at sea commercial length measurements of each species of wolffish by year, Subarea/Division, and fishing gear type.

In addition to NAFO, ZIF/MARFIS, and Fisheries Observer data, *SARA* logbook data from NL fishers aboard > 35 foot vessels fishing in Canada's EEZ were analyzed to evaluate the physical condition of wolffish upon release at sea. The proportion of wolffish released alive (by species) was calculated as a percentage of the total number of wolffish caught for each available year (2004-12).

UPDATE ON BIOLOGICAL RESEARCH - IMPACT OF HYPOXIA ON WOLFFISHES

Levels of dissolved oxygen (DO) are typically low in the deep waters of the Estuary and Gulf of St. Lawrence, a phenomenon known as hypoxia (Gilbert et al. 2005, 2007). Except near Cabot Strait, where DO levels in the Laurentian Channel are within the 40–55% sat. range, field values of DO near the bottom are usually below 40% sat. at depths greater than 175 m and are often below 30% sat. The most hypoxic zones are the St. Lawrence Estuary (18–25% sat.) and the head of the Esquiman and Anticosti Channels (20–30% sat.). Hypoxia can have many negative impacts on fish, including a reduced growth rate, and if severe enough, it can be lethal (Fry 1971). However, fish species can be very different in their susceptibility to hypoxia. As all three species of wolffishes do encounter low levels of DO in the Gulf of St. Lawrence, it is important to learn about their hypoxia tolerance and about the possible impacts of sublethal hypoxia.

Hypoxia Tolerance

Hypoxia tolerance of Atlantic and Spotted Wolffish has been studied at the Maurice-Lamontagne Institute over the last few years. A first LC_{50} (median lethal concentration, Plante et al. 1998) study dealt with juvenile Atlantic Wolffish. Twenty juveniles (20–40 g) were placed directly (no acclimation) into each of 6 tanks. DO levels were 16, 22, 28, 34, 40 and 100% sat at 10°C and a salinity of 29 ppt. These DO levels are available to Atlantic Wolffish in the Gulf of St. Lawrence, but at lower temperatures and higher salinity (4–6 °C and salinity of ~ 34 ppt; see Gilbert et al. 2005 and Galbraith et al. 2012). This high temperature was chosen because of the study's focus on the aquaculture potential of the species, and the higher growth rate observed at 10°C, rather than at colder temperatures. Survival was verified after many exposure durations but results are reported for 96 h. A similar study was completed on adult Spotted Wolffish (~2 kg). Ten fish were placed in each of 16 tanks, including 14 hypoxic tanks ranging from 15 to 28% sat., and two control normoxic tanks. A temperature of 8°C and salinity of ~ 28 ppt were maintained during these experiments. These DO levels are available to Spotted Wolffish in the Gulf of St. Lawrence at slightly colder temperatures. LC_{50} and LC_{05} after a 96 h of exposure were calculated by logit regression. A second type of hypoxia tolerance measurement, the critical oxygen level (O_{2crit}), was obtained for 2 size-classes of Spotted Wolffish (~2 and ~0.9 kg, respectively). O_{2crit} is obtained after determination of the Standard Metabolic Rate (SMR) of each fish by respirometry technique. SMR is the minimum level of energy expenditures in fish. It

is obtained in fish that are quiet, acclimated to the respirometer and in a postprandial (fasting) state (Fry 1971). Most fish are able to extract enough oxygen to maintain their SMR even as ambient DO level declines, but when hypoxia is too severe, their rate of oxygen consumption falls below SMR. The DO level at which oxygen consumption becomes proportional to DO is O_{2crit}. It is determined by slowly reducing ambient DO while measuring oxygen consumption and calculating the intersection of the regression line calculated over the data points where oxygen consumption is proportional to DO, and the horizontal line representing SMR (for an example, see Dupont-Prinet et al. 2013).

Hypoxia and Growth Rate

The impact of non-lethal levels of DO on the growth rate of Spotted Wolffish was studied for juveniles (~150 g initial mass) exposed to 40, 50, 60 or 100% sat. for more than 4 months, at 8°C and an average salinity of 28. These DO levels are common in the distribution of the Spotted Wolffish in the Gulf of St. Lawrence (see Hypoxia Exposure in the Results section). The fish were fed a commercial diet (Skretting Europa) ad libitum several times a day during week days and fasted during weekends. Fish were weighed periodically and the specific growth rate (SGR) of each fish was calculated using these equations (Hopkins 1992; Elliott and Hurley 1995; Peck et al. 2003):

$$IGR = [\ln(M_f) - \ln(M_i)] \cdot (t_2 - t_1)^{-1}$$
$$SGR = 100 \cdot (e^{IGR} - 1)$$

where IGR is the instantaneous growth rate, M_i and M_f is the initial and final mass, t_1 and t_2 are the dates at the beginning and end of the experiment, and *e* is a constant (the base of the natural logarithm).

Hypoxia Exposure

Hypoxia is an environmental stressor known to influence survival, growth rate and productivity of aquatic species (Fry 1971), as well as productivity and biodiversity of ecosystems (Diaz and Rosenberg 1995). Hypoxia typically occurs where the water column is stratified and exchanges between surface and deep water are reduced. In this situation, oxygen consumed in the bottom layer is not replenished.

Hypoxia is not a problem for Wolffish in Canadian waters, with one exception, the GSL. The GSL (including the estuary) is characterized by three deep troughs: the Laurentian, Anticosti and Esquiman Channels. The deep water in these channels is of Atlantic origin. A mix of Labrador Current water (cold, rich in oxygen) and North Atlantic central water (warmer, unsaturated in oxygen) enters into the GSL through the mouth of the Laurentian Channel and moves towards the head of the channels (Lauzier & Trites, 1958; Bugden, 1991; Gilbert et al., 2005). DO levels decrease progressively along the way because of respiration by fish and aquatic invertebrates, but mostly because of bacterial respiration (decomposition of organic matter which sinks to the bottom) (Coote & Yeats, 1979; Gilbert et al., 2005). Since the mid-1980s, DO levels have been around 55–60% saturation (sat.) at Cabot Strait, but only 18–30% at the head of the channels (Gilbert et al., 2005; Galbraith et al., 2012).

DO data from a variety of DFO surveys were compiled by Dutil et al. (2013). Average values were then calculated for each of the 10 x 10 km cells covering the GSL. These authors also summarized many other physical parameters (including temperature, salinity, depth) and abundance of each of the 3 wolffishes for each cell. These authors considered 4 DO classes: < 35%, 35–55%, 55–75% and > 75%.

RESULTS AND DISCUSSION

DISTRIBUTION AND ABUNDANCE

Central and Arctic Region

The three wolffish species are found in NAFO Subarea 0. However, abundances are low, and no directed fishery has ever occurred. Research surveys conducted by DFO in 1978-2010 caught Northern, Spotted, and Atlantic Wolffish in Subarea 0, but close to the boundaries of Subarea 1 (Greenland waters) and Div. 2G; possibly reflecting extensions of stocks from one or both of these areas (Fig. 3). Catches of Northern and Spotted Wolffish were limited to southern areas in Div. 0A, but occurred throughout Div. 0B. Spotted Wolffish were also caught in Div. 2G and Hudson Strait, but catches of Northern Wolffish were very limited in Hudson Strait, and none were caught in Div. 2G. Atlantic Wolffish were caught in research surveys in Div. 0B, Div. 2G, and Hudson Strait. Northern Wolffish were caught in 200-1100 m depths, Spotted Wolffish were caught in 200-700 m, and Atlantic Wolffish were caught in 200-500 m.

Area of occupancy (AO) for each species has increased since 2006, because the survey expanded into the Hudson Strait and Div. 2G in that year, and coverage of these areas has continued since. AO values in Subarea 0 are essentially unchanged.

Newfoundland and Labrador Region

The overall geographic distribution of catch from bottom trawl surveys showed that Northern Wolffish occur mostly from the northern boundary of the Grand Bank (Div. 3L) through the Northeast Newfoundland shelf to the southern Labrador shelves (Div. 2J3K; Fig. 4a,b). Northern Wolffish were nearly absent from tows in most southern areas (spring and fall), and, when catches do occur, they are along the shelf slope of the Grand Banks and Laurentian Channel (Div. 3NOP). Surface plots indicated that, in both Engel and Campelen time-series, Northern Wolffish were found along the shelf edge from the southern Labrador shelf (Div. 2J) to southern Grand Bank (Div. 3NO), and in the Hamilton Channel and Bonavista Corridor (Engel series) over the continental shelf. However, since the mid-1990s (Campelen series) when abundance indices reached the lowest survey estimates, those areas were reduced to a few geographic locations along the shelf edge adjacent to the tail of the Grand Bank, Flemish Cap, and Northeast Newfoundland and southern Labrador shelves.

The overall geographic distribution for Spotted Wolffish was similar to that of the Northern Wolffish. High density tows were observed mostly in the area adjacent to the northern Grand Bank (Div. 3L), Labrador shelf (Div. 2GHJ) and the Flemish Cap (Div. 3M) prior to 1995 (Engel series); whereas low density tows were found scattered throughout Div. 3K (Fig. 5a). Spotted Wolffish were uncommon elsewhere in the survey during both spring and fall, and were limited to the shelf slope (Div. 3NOP). Likewise, similar distribution patterns were observed in more recent periods (Campelen series, Fig. 5b).

Atlantic Wolffish occur in more shallow waters, notably over the southern Grand Bank (Div. 3NO), relative to Northern and Spotted Wolffish in both spring and fall surveys but the highest densities were observed in the northern Grand Bank (Div. 3L), the Flemish Cap (Div. 3M), and the Northeast Newfoundland and Labrador shelves (Div. 2GHJ3K, Figs. 6a,b). In both annual surveys, Atlantic Wolffish were caught over a broad range of depths. Furthermore, high density tows occurred in more recent periods (Campelen series) in Subdiv. 3Ps and Subdiv. 3Pn during spring surveys and in fall surveys on the southern Grand Bank.

Recent (2009-12) Canadian spring survey catches are illustrated in Figs. 7-9 for Northern Wolffish, Spotted Wolffish, and Atlantic Wolffish, respectively. These survey catches indicate a pattern similar to the general trends seen in previous years for each species, with Northern

Wolffish and Spotted Wolffish rarely occurring in Div. 3LNO and Subdiv. 3Ps. Where catches do occur, they are limited to deeper waters of the shelf slope. However, Atlantic Wolffish are found in shallower waters throughout Div. 3LNO, and especially in Subdiv. 3Ps.

Recent (2008-11) Canadian fall survey catches are illustrated in Figs. 10-12 for Northern Wolffish, Spotted Wolffish, and Atlantic Wolffish, respectively. These survey catches show a pattern similar to the general trends seen above in each species; with Northern Wolffish and Spotted Wolffish occurring mainly in Div. 2J3KL. Where catches do occur in Div. 3NO, they are also limited to deeper waters of the shelf slope. As observed in spring surveys, Atlantic Wolffish are found in shallower waters throughout Div. 2J3K and Div. 3LNO.

The area of occupancy (A_t) for Northern Wolffish declined the most in Div. 2J3K (fall surveys), falling from 76% in 1977 to < 1% in 2003; then increasing to 11-20% (Fig. 13). This general increasing trend in the area occupied has continued in recent years. There has been no real increase in the area occupied in the more southern areas of Div. 3LNO where Northern Wolffish are limited to deeper waters along the shelf edge. For Spotted Wolffish, a similar pattern in area occupied occurred (Fig. 14). For Atlantic Wolffish in Div. 2J3K (fall surveys) and Div. 3LNO (fall and spring surveys), A_t has generally remained stable over the last 15-20 years (Fig. 15).

Mean catch per tow for Northern Wolffish was highest in Div. 2J3K at the onset of the fall survey, when compared to fall and spring indices on the Grand Bank (Div. 3LNO) and the spring index in Subdiv. 3Ps (Figs. 16a,b). In recent years, there has been a very gradual increase in catch rates during the spring survey in Div. 3LNO. Similarly, a very slight increase was seen over similar time periods during the fall survey in Div. 2J3K and Div. 3LNO. In Subdiv. 3Ps, where Northern Wolffish is rarely caught, catch rates appeared lower but less variable in recent years.

Historically, trends in Spotted Wolffish abundance indices varied similar to those for Northern Wolffish: during the fall surveys, they were highest in Div. 2J3K during the late 1970s, but declined steadily through the 1980s (Figs. 17a,b). Following a general increase in Div. 3LNO during the spring survey over 1995-2006, catches of this species declined in recent years. The abundance index in Subdiv. 3Ps fluctuated without trend throughout the spring time series. Since the late 1990s, catch rates of Spotted Wolffish generally increased in the fall surveys of Div. 2J3KLNO.

For Atlantic Wolffish (Figs. 18a,b), catch rates in recent years have been relatively stable in both spring and fall surveys.

Northern Wolffish are still found along the shelf slope and into the outer extent of troughs separating the banks (Hopedale, Cartwright, and Hawke Channels, and Funk Island Deep). In previous years when abundance was higher (1978-84), their distribution extended farther into troughs and channels and over the banks and shallower waters (Kulka et al. 2004b). Northern Wolffish experienced the largest reduction in area occupied (> 99%) for these three species. The area occupied has generally increased, especially in Div. 2J3K, since 1995; over roughly the same period, there has been a general trend of increasing abundance.

The current distribution of Spotted Wolffish in Subareas 2 and 3 is similar to that observed for Atlantic Wolffish, except for the southern Grand Bank. Since 1995, the area occupied by Spotted Wolffish increased steadily, particularly on the northeast Newfoundland Shelf, and the northern edge of the Grand Bank. The greatest increase occurred when this species occupied 37-49% of the area surveyed in 2008-09; within the range observed during years of peak abundance (48%) in 1978-84, and consistent with recent increases in abundance indices from both spring and fall surveys.

Atlantic Wolffish are presently found over most of the survey area; except on the inner portions of the banks, and along much of the coastal areas. In addition, Atlantic Wolffish continued to

occupy the shallow portion of the southern Grand Bank, an area where the other two species rarely occur. Since 1995, there has been little change observed in their distribution, and area occupied in the fall ranged between 60-73% (Div. 2J3KLNO) in 2007-09, which is greater than that observed during years of peak abundance (57%) in 1978-84 (Kulka et al. 2004b).

Relative to the other species, research survey indices of relative abundance and distribution for Atlantic Wolffish have varied the least over different time periods; particularly on the Grand Bank (1975-2012) and the northeast Newfoundland and Labrador shelves (1995-2011). Indices of relative abundance for Northern Wolffish declined the most over the same period.

Overall, recent trends in Canadian survey indices suggest that population abundances of the three species of wolffish inhabiting Newfoundland and Labrador waters are no longer declining, and some initial signs of recovery were detected throughout the survey area. Indices of relative abundance and distribution indicated increasing trends since the early 2000s, as wolffish began returning to several historical areas and showed distribution patterns similar to those observed during periods of high abundance.

Gulf Region

Northern Wolffish were not abundant in the GSL during 1978-2012. They were virtually absent from the southern GSL; except for a few catches on slopes of the Laurentian Channel. Most individuals were captured on slopes or on the shelf off of the southwest coast of Newfoundland. Though more common than Northern Wolffish, Spotted Wolffish were also virtually absent from the southern GSL in 1978-2012. Most catches were recorded in the northeastern part of the GSL, on slopes of the Esquiman Channel, and on the shelf off of the Newfoundland west coast. Atlantic Wolffish were more widespread in the GSL, except in the Estuary (where it is known to occur, but has never been captured in research surveys). This species was most abundant on upper slopes of deep channels and on the shelves; especially the shelf off of Newfoundland's west coast. Spotted and Atlantic Wolffish showed a large degree of spatial overlap, with Atlantic Wolffish occurring more closely to coastlines, and avoiding deep channels.

Northern Wolffish were caught only occasionally during summer surveys of the northern GSL (Div. 4RS); thus, no trend was apparent (Fig. 19). Northern Wolffish were not observed in the southern GSL. Mean abundance of Spotted Wolffish was particularly low over 1990-96 in Div. 4RS (northern GSL), with a trend toward higher abundance afterwards; albeit only about 0.25 kg per tow (Fig. 20). Atlantic Wolffish was slightly more abundant at approximately 0.5 kg per tow in Div. 4RS (northern GSL; Fig. 21). No trend was visible over 1990-2012. This is the only wolffish species caught in research surveys of the southern GSL in Div. 4T (Fig. 22). Abundance indices were low over 1970-2012, although the period of 1989–97 was characterized by higher abundances.

Northern Wolffish has always occupied a very small proportion of the northern GSL, but it became even rarer at the end of the 1980s: found in only 4 sets during 1990-2012 (Fig. 23). It is unclear whether the larger area of occupancy prior to 1990 represents a more abundant population, or a change in survey design and gear. In 1978-2012, Spotted Wolffish occupied an average of 4.1% (±3.2 SD) of the surveyed area of the northern GSL (Fig. 24); suggesting a reduction in area of occupancy. This coincides with the collapse of other demersal fishes (e.g., Atlantic Cod) in the northern GSL during the early 1990s (Fréchet et al. 2009). In recent years, there appeared to be a return to an area of occupancy typical of the 1980s (5–6%). Changes in survey vessels and gear may have caused some of these differences, but data covering this entire period (i.e., indicating very low area of occupancy and the apparent beginning of recovery) were collected with the same vessel and gear (RV *Alfred Needler*; 1990-2003). Area of occupancy for Atlantic Wolffish was 15.8% on average (±5.4 SD; Fig. 25). It was lowest in 1990-95 but, by the late 1990s, returned to values similar to those observed in 1978-89.

In the Gulf Region, both Northern and Spotted Wolffish are captured infrequently in research surveys, while Atlantic Wolffish are more common. Indices of abundance of Atlantic Wolffish, for both Div. 4RS and Div. 4T, have varied without trend for the duration of each survey time series.

Maritimes Region

Summer Survey of the Scotian Shelf (Div. 4VWX, and a small portion of 5Y)

The Summer RV Survey is the longest running survey series in the Maritimes Region having been conducted annually in July since 1970. There are no records of either Northern or Spotted Wolffish from this survey. Simon et al. (2011) observed that out of the 7,200 sets completed during 1970–2010, 1,379 sets or 19.2% captured Atlantic Wolffish. They noted that the composite distribution pattern revealed two primary areas of concentration: the eastern Scotian Shelf including Div. 4Vn and on the western Scotian Shelf (Div. 4X), primarily Brown's Bank. Consistent with the methodology of Simon et al. (2011), the distributional data was then separated into immature (1-53 cm) and mature (> 53 cm) individuals. The distribution of immature individuals was similar to the overall distribution pattern, while the abundance of mature individuals appeared to be higher in Div. 4X. The distributional results from 2011 and 2012 surveys were consistent with the historical observations (Figs. 26 and 27). Abundance was highest on LaHave Bank and in Div. 4V (Fig. 27). Very few mature Atlantic Wolffish were observed in Div. 4V.

The abundance index (#/tow) for Atlantic Wolffish in Div. 4VWX (and a small part of Div. 5Y) is shown in Fig. 28. The annual mean number per tow from the survey was adjusted using areal expansion into total abundance of immature and mature Atlantic Wolffish for Div. 4VW and Div. 4X and then for the entire survey area (Div. 4VWX) (Fig. 29). Note that in all cases the deep-water strata that have been sampled since 1995 were not included in the abundance estimates although they have been included in the distribution maps. The historical patterns in abundance from 1970-2010 were described by Simon et al. (2011). In Div. 4X, abundance of immature fish was high in 2011 but returned to very low estimates in 2012. In Div. 4VW, immature fish abundance was similar to the previous two years and mature fish abundance continued to be very low. The overall abundance trends for immature and mature individuals for the Scotian Shelf (Div. 4VWX) are similar to the trends observed in the previous analysis. The number of immature and mature individuals as estimated by the survey has averaged 2.5 and 0.2 million, respectively since 2002.

The log transformed catch rates of Atlantic Wolffish for the entire survey period, as well as for three generations, are similar to those observed by Simon et al. (2011). For the entire survey period (1970-2012, 43 years), figures are presented for all size classes combined, and for mature fish only in Div. 4X, Div. 4VW and Div. 4VWX (Table 2; Fig. 30). These data suggest that the eastern and western Scotian Shelf exhibited different responses during the survey series. In Div. 4X, the decline when all length groups were considered was 69%, while there was a decline of 83% in the mature length group. In Div. 4VW, there was an overall increase in the total numbers at length of 34%, but the decline in the mature fish abundance was 95%. When the Scotian Shelf is considered as a whole (Div. 4VWX), the abundance of mature fish declined by 92%.

Similar changes in abundance for the summer survey were calculated for a period of three generations (1980-2012, 33 years). In Div. 4X, the decline in the total and mature abundance was 67 and 83%, respectively. In Div. 4VW, the total number increased by 22% over the period, while the mature abundance declined by 95%. When the Scotian Shelf is considered as a whole, the decline in total abundance and mature abundance was 32 and 92%, respectively (Table 2; Fig. 31).

The area of occupancy based on the summer RV survey from 1970 to 2010 was updated for the western Scotian Shelf (Div. 4X), the eastern Scotian Shelf (Div. 4VW), and the entire survey area (Div. 4VWX) (Fig. 32). In Div. 4X, the area occupied continued to decline, so that the 2012 survey estimate was the second lowest in the series. On the eastern Scotian Shelf, the area occupied had not shown any significant trend over the survey series, averaging close to 20,000 km^2, but the 2011-12 estimates declined to the lowest observed in the series. When the entire survey is considered, area occupied has declined from an average of approximately 45,000 km^2 in the 1970s, to an average of approximately 20,000 km^2 from 2009-11. In 2012, the estimate was approximately 10,000 km^2.

Winter Survey of Georges Bank (Subdiv. 5Ze)

There were no records of Northern or Spotted Wolffish from the Georges Bank RV survey. Atlantic Wolffish were primarily distributed north of the Great Southwest Channel, especially close to Cape Cod and on the northern half of the Northeast peak of Georges Bank (Simon et al. 2011). There is a break in distribution between the Canadian and USA sides of the bank. Since 2008, only two Atlantic Wolffish have been caught, one during each of the 2011 and 2012 surveys (Fig. 33). Therefore the abundance estimates for both length groups continue to be extremely low (Fig. 34).

On the Canadian portion of Georges Bank (Subdiv. 5Zc), the area of occupancy has declined from approximately 6,000 km^2, in the late 1980s, to zero by 2009 and has remained low during the last two years of the survey (Fig. 35).

4VsW Sentinel Survey of the Eastern Scotian Shelf (Longline)

There were no reports of Northern Wolffish from this survey in either 2010 or 2011. There was one report of a Spotted Wolffish from a shallow water strata along the eastern shore of Nova Scotia (Fig. 36) in 2010. The distribution of Atlantic Wolffish, as indicated by the 4VsW Sentinel Survey from 1995 to 2009, was concentrated north of Banquereau and Middle Banks, as well as in the inshore strata less than 50 fathoms (Simon et al. 2011). The area surveyed since 2005 does not sample the distribution of Atlantic Wolffish in the offshore area. In 2010 and 2011, four Atlantic Wolffish were caught in the inshore strata during the survey and one on Western Bank (Fig. 37).

4Vn Sentinel Survey (Longline)

A total of nine Northern Wolffish were identified during this survey. These fish were distributed near shore as well as near the 100 m depth contour (Fig. 38). Given the preferred depth range of this species it is possible that the nearshore observations are misidentified. A total of 60 Spotted Wolffish were identified during the survey. These fish were distributed throughout the survey area (Fig. 38) and, although it is possible that they are also misidentifications, the industry technician for the fishery indicated that both species were caught as bycatch in the survey.

Although Atlantic Wolffish are distributed throughout the survey area, their abundance is highest in the southern half of the survey area in the area of the proposed St. Ann's Bank MPA (Fig. 39). Atlantic Wolffish were caught in 28% of the survey sets. Average catch rate (kg/tow) was highest in 1994, declined to less than 2 kg/tow in 2000, and has remained steady since then (Fig. 40).

Information to estimate area of occupancy was not available for the 4Vn Sentinel Survey, so the percentage of sets in which Atlantic Wolffish occurred in this survey was used. The percentage of sets occupied during the 4Vn Sentinel Survey has remained steady near 25% (Fig. 41).

Halibut Survey of the Scotian Shelf and Southern Grand Banks (Div. 3MNOP4VWX)

Distribution (kg/tow) from the fixed station and commercial index portions of the halibut longline survey during 2010-12 revealed that Northern and Spotted Wolffish were caught in areas previously described by Simon et al. (2011), primarily on the edges of the Scotian Shelf and the Grand Bank (Fig. 42, Fig. 43).

The distribution of Atlantic Wolffish as indicated by the fixed station portion of the halibut longline survey in 2010 and 2011 was similar to that observed by Simon et al. (2011), although abundance appeared to be concentrated in Subdiv. 3Ps and Subdiv. 4Vs. The distribution of Atlantic Wolffish appears to be more restricted during the index fishery portion of the survey than in previous years, with the species again being primarily distributed in Subdiv. 3Ps and Subdiv. 4Vs (Fig. 44).

Stratified mean catch (kg) per tow from the fixed station portion of the survey for the entire survey area was generally less than 2 kg/tow until 2011, when it peaked at greater than 9 kg/tow. In 2012, the abundance declined again, to less than 2 kg/tow (Fig. 45).

Information needed to estimate area of occupancy was not available for the halibut survey, so the percentage of sets with Atlantic Wolffish was used. In the Halibut Fixed Station Survey, wolffish occurred in approximately 20% of the sets in Div. 4X, and slightly less than 10% in Div. 4VW (Fig. 46). No trends were evident in either area.

Snow Crab Survey of the Scotian Shelf (Div. 4VWX - Otter trawl)

No Northern Wolffish were caught in the survey in either 2010 or 2011, and only one Spotted Wolffish was caught in the 2010 survey in the proposed St. Ann's Bank MPA.

The distribution of Atlantic Wolffish from 2010 to 2012 during this survey was similar to that observed by Simon at al. (2011) from 2004-09. Atlantic Wolffish were broadly distributed throughout Subdiv. 4Vn and the northern half of Subdiv. 4Vs. They were scattered throughout the remainder of the surveyed area (Fig. 47).

ITQ Survey of the Southwestern Scotian Shelf (Div. 4X - Otter trawl)

There were no reports of either Northern or Spotted Wolffish during the ITQ survey between 2010 and or 2012.

Abundance of Atlantic Wolffish during this survey was very low in 2010-12. The species was only observed at five locations scattered across the Scotian Shelf in Div. 4X and near the Crowell Basin (Fig. 48). Mean weight (kg) per tow for the survey has declined from near 3 kg/tow to less than 0.1 kg/tow in 2012 (Fig. 49). In 2011, no Atlantic Wolffish were caught by the survey (Fig. 49).

Information to estimate area of occupancy was not available for the ITQ survey, so the percentage of sets in which Atlantic Wolffish occurred in those surveys was used. The percentage of sets occupied during the ITQ Survey has declined from an average of about 15%, from 1995 to1999, to less than 5% in the last 7 years (Fig. 50).

COMMERCIAL FISHERIES REMOVALS

Commercial fisheries data for wolffish are unspeciated (except for Canadian Fisheries Observers' data): all three species are recorded by fishers as "Catfish" or "wolffish-unspecified". Canadian fisheries targeting wolffish in Canada's EEZ are very limited; thus wolfish landings are almost always recorded as bycatch in fisheries targeting other commercial species. Since 2003, with the passage of Canada's *SARA*, landings have consisted solely of Atlantic Wolffish due to mandatory release of both Northern Wolffish and Spotted Wolffish (Table 3). It is thus assumed that fishing mortality of Northern and Spotted Wolffish has been reduced in Canada's EEZ.

Throughout the entire Canadian zone of interest (NAFO Subarea 0 and Divisions 2GH, 2J3K, 3LNO, 3P, 4RST, 4VWX, and 5YZ), reported landings of wolffish peaked at 12,000 t in 1971, and subsequently declined (Fig. 54). Northwest Atlantic Fisheries Organization data from 1960 to 2011 indicated that reported landings of unspeciated wolffish in Subarea 2 and Div. 3KL averaged 1,214 t and 2,057 t (respectively) in 1973-76, and 1,472 t in 1967-85 (Fig. 55). By 2008-10, total NAFO-reported wolffish landings in Subarea 2 and Div. 3KLNOP were 187 t, and 973 t in 2011. In addition, wolffish landings reported without fishing location averaged 303 t in 1994-2003, and peaked at 1,134 t in 2009. Canadian commercial landings from Subareas 4 and 5, from NAFO and DFO databases, are presented in Fig. 56. In Div. 5Z, landings have generally been below 100 t since 1963, and near zero in recent years. In Div. 4X5Y, landings increased from 400 t in the early 1960s to a peak of 1600 t in the late 1970s. Landings then declined to an average of 400 t in the 1990s, and have continued to decline to near zero in recent years. In Div. 4VW, landings peaked at roughly 700 t in the early 1970s, declined to less than 400 t in the late 1970s, and rebounded to 700 t in the early 1980s. Landings declined sharply until 1993 when all directed fishing for cod and haddock ended and, since 1993, have remained near zero

According to ZIF data, Canadian fisheries landed 40 tons of unspeciated wolffish in 1988, and 18 t in 1992 (Fig. 57). Wolffish were typically reported as bycatch in other Canadian fisheries prosecuted in Subareas 2 and 3 from 1985 to 2011. In 1985-91, an average of 960 t was landed, with a peak of 1,351 t in 1987. In 1999-2002, 382 t of wolffish were landed, on average, with a peak of 450 t in 2002. Reported landings for all areas declined by 2004, and averaged only 24 t annually over 2004-11.

With respect to areas fished, Canadian reported landings of unspeciated wolffish in Subarea 2 and Div. 3KLNO of Canada's EEZ averaged 1,132 tons in 1985-89, with a peak of 1,351 t in 1987 (Fig. 58). Canadian landings decreased almost to zero in 1994-97. In 1998-2002, wolffish landings averaged 337 t in Div. 3KLNP, with 226 t in Div. 3P alone. By 2004, reported landings fell to zero in Div. 3KLN, and averaged 24 t in Div. 3P from 2004-11.

Regarding fishing gears used in Canada's EEZ, Canadian fishers deployed primarily bottom trawls in 1985-93, averaging 803 tons annually, with a peak of 1,075 t in 1987 (Fig. 59). In 2001-02, reported landings of wolffish from trawls averaged 190 t (peaked at 274 t in 2002); and landings decreased to zero by 2004. Gillnets landed an average of 156 t annually in 1985-89; with very low values reported after 1990. Wolffish landings from longlines were rare until 1998, whereupon a 210 t average was reported in 1998-2002, with a peak of 339 t in 2000. Reported landings from longlines averaged 26 t annually during 2003-11.

At-sea speciated wolffish catch data collected by Canadian Fisheries Observers in Div. 2GHJ3KLNOP (within EEZ) suggested that Northern Wolffish was the predominant wolffish species captured (as bycatch) in 1985-92; averaging 1,088 tons annually, with peaks of 1,898 t and 996 t in 1987 and1991 respectively (Fig. 60). In 1993-2009, average annual catch decreased to 77 t, and no catches were recorded for 2010-11, a period associated with a decline in Observer coverage for particular fisheries. In 1985-91, bycatch of Spotted Wolffish averaged 636 t; with peaks at 735 t and 712 t in 1989 and 1991, respectively. Average catch of Spotted Wolffish decreased to 32 t in 1992-2009 and, as with Northern Wolffish, there were no observed records in 2010-11. Since 1985, Observer data indicated that annual catches of Atlantic Wolffish were greatest in 2001-05, with a 371 t average, and a 628 t peak in 2004. Although no observer records for olffish exist for 2010, average annual catch was 69 t in 2006-11.

From 1985-91, at-sea observer data from Canada's EEZ also showed that total catch of Northern Wolffish averaged 515 t annually in Subarea 2, 439 t in Div. 3K, and 175 t in Div. 3L (Fig. 61). During the same period, total catch of Spotted Wolffish averaged 132 t annually in

Subarea 2, 244 t in Div. 3K, and 261 t in Div. 3L. Total catch of Atlantic Wolffish averaged 357 t annually during 2001-05 in Div. 3N, with a peak of 609 t in 2004.

Northern Wolfish ranged from 25-131 cm TL in observed catches from bottom trawls (including "twin" trawls) with 145-156 mm codend mesh fishing in Div. 2HJ3KL (Fig. 62). Gillnets with 152-203 mm mesh also caught this species in Div. 3K and length ranged between 47-123 cm. Longline gear fishing in Div. 2GH3O caught Northern Wolffish between 39-132 cm , and pots with 127-152 mm mesh fishing in Div. 2HJ3K caught this species in the 35-125 cm size range. Spotted Wolffish, ranging between 41-134 cm TL, were caught by bottom trawls with 145-156 mm codend mesh fishing in Div. 2J3KL (Fig. 63), gillnets with 152-162 mm mesh caught Spotted Wolffish between 30-118 cm in Div. 3L, longlines caught a 51-160 cm range in Div. 3O, and pots with 130-152 mm mesh caught a 31-117 cm range in Div. 2J3KL. Atlantic Wolffish measuring 35-130 cm TL were caught by bottom trawls with 145-156 mm codend mesh fishing in Div. 3NOPs (Fig. 64). For gillnets with 135-165 mm mesh in Div. 3LPs, the length range for this species was 40-106 cm range, for longlines in Div. 3P the range was 28-130 cm , and for pots with 130-152 mm mesh in Div. 3K the range was 36-104 cm .

Observer data also showed that the shrimp trawl, unlike other commercial fishing gears, does catch wolffish young-of-the-year (YOY). A size range of 5-25 cm TL for the three wolffish species was retained by shrimp trawls fishing with a 40-50 mm codend mesh in Div. 2GHJ3K (Fig. 65). However, mature wolffish were not retained by this gear, due to a groundfish excluder (i.e., Nordmore grate) installed below a "bycatch exit window" in the trawl.

Analyses of Fisheries Observer data suggested that an average of 441 t of wolffish was discarded annually at sea in Div. 3L over 1986-91 (Fig. 66), 628 t in 1985 and 875 t in 1994 were discarded in Subarea 2, a 475 t average was discarded in Div. 3K over 1998-2002 (with a 1,128 t peak in 1999), and a 162 t average in Div. 3N in 2004-06. By 2006, wolffish discards in all areas of Canada's EEZ (combined) decreased to approximately 200 t annually.

Species at Risk Act logbook data from NL fishers aboard > 35 foot commercial vessels fishing in Canada's EEZ are presented in Table 4 and Fig. 67. The percentage of Northern Wolffish released alive at sea increased from 30% in 2004 to 92% in 2008-09, and declined considerably since then. In contrast, over 90% of Spotted Wolffish caught in 2004-11 were released alive. For Atlantic Wolffish, which can be commercially retained under *SARA*, the percentage released alive during 2005-09 averaged 91% annually but has declined steadily since then. In addition, there were increasing trends in the number of Northern, Spotted, and Atlantic Wolffish being recorded in *SARA* logbooks over 2004-11. Incomplete data for 2012 indicated that recorded catches totalled 678 Northern (49% dead), 1,202 Spotted (14% dead), and 433 Atlantic Wolffish (58% dead). It is important to note that, in *SARA* logbooks, wolffish condition (i.e., alive vs. dead) is poorly defined. In addition, wolffish survival upon release is contingent upon a variety of factors, including physiological stress due to exposure to varying temperatures during fishing gear retrieval, as well as handling time. Live release does not guarantee post-release survival. Although completion of *SARA* logbooks is a condition of some commercial fishing licences for Canadian waters, these data do not represent all wolffish fishing mortalities, and do not reflect mortalities that occur regularly outside Canada's EEZ.

UPDATE ON BIOLOGICAL RESEARCH - IMPACT OF HYPOXIA ON WOLFFISHES

Hypoxia Tolerance

Juvenile Atlantic Wolffish (20–40 g) were exposed to different hypoxia levels at 10°C and survival was assessed after 96 h (Le François et al. 2001). A true LC_{50} (median lethal concentration) was not calculated because of the coarseness of the DO levels, but the lethal

threshold was between 16 and 22% sat., as all 20 fish exposed to the lower level died, whereas 19 of the 20 fish exposed to 22% survived. No mortality occurred above 22% sat.

Jetté et al. (2011) studied hypoxia tolerance in the Spotted Wolffish. The 96 h LC_{50} and LC_{05} of adult (~2 kg) fish at 8°C were 20.9% and 26.1% sat., respectively. The O_{2crit} of adult Spotted Wolffish (2275 ± 672 g, mean ± SD, N = 21) was 16.9 ± 3.8% sat. Smaller juvenile Spotted Wolffish (753 ± 69 g, N = 78) were less tolerant to hypoxia, with an O_{2crit} of 30.8 ± 1.6% sat. (Schouman 2012). As oxygen consumption per g of tissue is greater in smaller fish younger individuals are often less tolerant of hypoxia than older ones (Dupont-Prinet et al. 2013).

There is no data on hypoxia tolerance in the Northern Wolffish, but its distribution in the GSL encompasses the deep channels where DO levels are very low, which suggests it is at least as hypoxia-tolerant as the Spotted Wolffish.

Hypoxia and Growth

Juvenile Spotted Wolffish from Norway (initial mass of ~69 g) were reared at different DO levels (42, 62 and 100% sat.) for 11 weeks at 8°C. Final mass, specific growth rate (SGR) and food consumption were all significantly reduced at the two hypoxia levels compared with the control group. SGR was less at 42 than at 62% sat. Similar results were obtained with juvenile fish of GSL origin. The final mass was significantly different between all treatments, and proportional to DO level (Fig. 68). SGR was proportional to DO below ~70% sat. (Fig. 69). This reduced growth rate in hypoxia is accompanied by a reduced rate of food consumption, which is caused by a prolonged period of digestion in hypoxia. Fish have to increase their rate of oxygen consumption after ingesting a meal. But at 40% sat., juvenile Spotted Wolffish (~850 g) were not able to increase their oxygen consumption as much as they did in normoxia: peak oxygen consumption was increased by only 50% in hypoxia, compared with 100% in normoxia) and as a result, it took much longer for oxygen consumption to return to baseline level (168 vs 101 h), which is interpreted as a limitation on the rate of food consumption (Christen 2012).

Hypoxia Exposure

The Area of Occupancy of Atlantic Wolffish in the GSL is 61% on shelves, 14% on the slopes of the Laurentian and Esquiman Channels, and 26% in the Channels (Dutil et al. 2013). As such, it is not often exposed to hypoxia. Only 4% and 40% of its area of occupancy were characterized by DO levels < 35% and 35–55%, respectively. About 28% of the area of occupancy corresponded to each of the other two DO classes (55–75 and > 75% sat.) (Dutil et al. 2013). Hypoxia avoidance was more pronounced when only the most important areas (hot spots) were considered: 1, 31, 36 and 33% of the hot spots corresponded to the 4 DO classes.

The Spotted Wolffish is rare in the western and southern part of the GSL, being almost restricted to the northeast part of the GSL, on both sides of and in the Esquiman Channel (Dutil et al. 2011, 2013). The area of occupancy is mostly on shelves (49%) and in deep channels (41%), with 10% of the surface area on slopes (Dutil et al. 2013). The proportion of the area of occupancy found in each of the 4 DO classes (< 35, 35–55, 55–75 and > 75% sat.) is 6, 42, 28 and 24%, respectively. In terms of hot spots, the proportion of their total area found in each of the 4 DO classes is 6, 37, 27 and 30%, respectively. Almost half of the area that is most frequented by the Spotted Wolffish is characterized by DO levels < 55% sat.

The Northern Wolffish is quite rare in the GSL, but the area of occupancy is mostly (59%) in the Laurentian and Esquiman Channels, whereas 28% is on the shelf (mostly southwest of Newfoundland) and 20% is on slopes (Dutil et al. 2011, 2013). The proportion of the area of occupancy characterized by each of the 4 DO classes is 9, 50, 26 and 16%. In terms of the proportion of the hot spots' total area, the 4 DO classes correspond to 7, 50, 30 and 13%. The majority of the sites most frequented by Northern Wolffish have DO levels < 55% sat.

CONCLUSIONS

This paper presents the most recent information on the distribution, abundance, area of occupancy, and fishery removals, of three wolffish species in the Canadian Arctic and Northwest Atlantic Oceans, explores a potential method for deriving biological reference points required for application of the Precautionary Approach to wolffish species; and provides new biological information, in support of the 5-year review of progress made toward satisfying objectives laid out in the Recovery Strategy and Management Plan.

The primary results can be summarized as: (i) in recent years there has been no major change in the distribution of these three species; (ii) historically, the area centred north of the Grand Bank constitutes the most persistent location of high concentrations of Northern Wolffish and Spotted Wolffish, and on the southern Grand Bank for Atlantic Wolffish; (iii) significant declines in indices of relative abundance and area occupied by the three species occurred through the 1980s and early 1990s; and (iv) some signs of population recovery have been detected, particularly in the NL Region, where both indices of relative abundance and area occupied for Northern and Spotted Wolffish tended to increase in most areas surveyed during the last decade. However, other regions have experienced no increases in distribution or abundance indices in recent years.

Overall, reported wolffish landings declined substantially through the 1980s and early 1990s, mainly in southern Labrador and northern Newfoundland shelves (Div. 2J3KL). Reported commercial landings remained low through the 1990s, but increased in the early 2000s before declining abruptly thereafter. It should be noted that this decline in landings is a result of listing the three species of wolffish on Schedule 1 of *SARA*, and subsequent mandatory release of Northern and Spotted Wolffish in Canadian waters. It should also be noted that the degree of impact of removals (as bycatch and discards) by commercial fisheries on wolffish populations remains unknown.

The head of the Esquiman channel is severely hypoxic (< 25% sat.) and the survival of juvenile Spotted Wolffish could be compromised there, and possibly that of Northern Wolffish as well, as the hypoxia tolerance is likely similar to that of the other two species. Almost half of the area where Spotted Wolffish are most frequently encountered is characterized by DO levels that reduce growth rate in the laboratory. The proportion is even higher for the Northern Wolffish. However there are presently no data on growth rate of wild Spotted Wolffish living at different DO levels. Such a study is necessary to confirm that hypoxia has the same impact in the field as in the laboratory. The potential impact of DO on gonad maturation and fertility has not been studied. DO could also reduce egg development and hatching success, as it does for Greenland Halibut eggs (Mejri et al. 2012).

Hypoxia could become a greater problem in the future. Between 1930 and the mid-1980s, DO levels decreased by half in the deep water of the St. Lawrence Estuary due to an increase in the proportion of North Atlantic central water coming into the system and an increase in organic matter flow from the surface layer (Gilbert et al. 2005; Thibodeau et al. 2006; Gilbert et al. 2007). Dissolved oxygen levels declined in the GSL as well (Genovesi et al. 2011). As the drop in DO between the 1930s and 1980s was accompanied by a warming of the water (~1.7°C, Gilbert et al. 2005), respiration rates increased because chemical reactions, in general, and metabolic rate, in particular, tend to accelerate with temperature (Fry 1971). Therefore, increased respiration contributed to the decrease in DO that took place during this period (Genovesi et al. 2011). Since the mid-1980s, DO levels in the deep channels have been stable (Gilbert et al. 2007; Galbraith et al. 2012). However, climate change and increasing human population have the potential to further accentuate hypoxia in the St. Lawrence system. Growth rate and possibly fecundity and recruitment of Spotted (and probably also Northern) Wolffish could suffer.

In Canadian waters, wolffish are considered data-poor species: due to partial information or lack of knowledge of stock structure and several important aspects of life history (e.g. growth, reproduction, natural mortality), in addition to poor records from commercial fisheries. Such data are necessary to conduct a comprehensive assessment of stock status.

ACKNOWLEDGEMENTS

We thank Fisheries and Oceans Canada staff, who participated in Canadian research surveys; and Canadian Fisheries Observers, who collected data and specimens aboard commercial fishing vessels, under difficult conditions, over many years.

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Table 1. List of bottom trawl research surveys conducted in the Newfoundland and Labrador Region (NAFO Div. 2HJ3KLMNO and Subdiv. 3Ps) during the period 1971-2012. Various vessels and fishing gears were used over the years. Vessels: A.T. Cameron, Gadus Atlantica, Wilfred Templeman, Alfred Needler, Teleost. Gears: Yankee 41.5 otter trawl (yellow), Engel 145 otter trawl (green) and Campelen 1800 shrimp trawl (brown). White cell: no survey was conducted in the area/season/year. Winter/fall surveys (*). Spring surveys in 2006 were incomplete; data from these were not included in the analyses

	Spring Survey Series				Fall Survey (+3M Winter) series							
	3L	3N	3O	3Ps	2G	2H	2J	3K	3L	3M*	3N	3O
1971	✓	✓	✓									
1972	✓	✓		✓								
1973	✓	✓	✓	✓								
1974	✓	✓		✓								
1975	✓	✓	✓	✓								
1976	✓	✓	✓	✓								
1977	✓	✓	✓	✓			✓	✓		✓		
1978	✓	✓	✓	✓	✓	✓	✓	✓		✓		
1979	✓	✓	✓	✓	✓	✓	✓	✓		✓		
1980	✓	✓	✓	✓			✓	✓		✓		
1981	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
1982	✓	✓	✓	✓			✓	✓	✓	✓		
1983				✓			✓	✓	✓	✓		
1984	✓	✓	✓	✓			✓	✓	✓	✓		
1985	✓	✓	✓	✓			✓	✓	✓	✓		
1986	✓	✓	✓	✓			✓	✓	✓			
1987	✓	✓	✓	✓	✓	✓	✓	✓	✓			
1988	✓	✓	✓	✓	✓	✓	✓	✓	✓			
1989	✓	✓	✓	✓			✓	✓	✓			
1990	✓	✓	✓	✓			✓	✓	✓		✓	✓
1991	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
1992	✓	✓	✓	✓			✓	✓	✓		✓	✓
1993	✓	✓	✓	✓			✓	✓	✓		✓	✓
1994	✓	✓	✓	✓			✓	✓	✓		✓	✓
1995	✓	✓	✓	✓			✓	✓	✓		✓	✓
1996	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1997	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1998	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1999	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2000	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
2001	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
2002	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
2003	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
2004	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
2005	✓	✓	✓	✓			✓	✓	✓		✓	✓
2006	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
2007	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
2008	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
2009	✓	✓	✓	✓			✓	✓	✓		✓	✓
2010	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
2011	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
2012	✓	✓	✓	✓								

Table 2. Summary of percent change in abundance of Atlantic Wolffish from all length groups and mature lengths from the research surveys conducted within the Maritimes Region. Note that abundance was too low or sporadic for some surveys or for some mature length groupings to estimate a rate of decline.

Survey	Years	Area	Abundance Trend	
			All lengths	Mature
Summer RV	1970-2011 43 Years	4X 4VW 4VWX	-69 +134 -12	-83 -895 -92
Summer RV	1989-2012 33 years	4X 4VW 4VWX	-67 +122 -32	-83 -95 -92
4VW COD	1986-2010 25 years	4VsW	-58	N/A
Georges Bank	1986-2010 25 years	5z, Cdn	-99	N/A
US Fall	1963-2007 47 years	4X5YZ	-97	-99
US Fall	1975-2007 33 years	4X5YZ	-98	-99
US Spring	1968-2007 42 years	4X5YZ	-95	-99
	1975—2007 33 years	4X5YZ	-96	-99

Table 3. Reported landings (kg) of unspecified wolffish from 2002 to 2011. Data do not include discards at sea.

Division	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
0AB	.	.	.	.	.	.	.	.	.	.
2GH	.	.	.	.	.	.	.	.	.	.
2J3K	26	5	.	.	.	.	.	.	.	.
3LNO	805	725	384	246	29	94	198	115	155	162
3Ps	169	69	39	36	19	18	22	26	13	5
4RST	97	14	7	6	6	10	18	15	26	6
4VWX5Y	166	141	120	93	62	50	21	10	9	6
5Z	7	7	4	13	7	4	2	1	1	1

Based on NAFO STATLANT 21A, Dec. 4, 2012, except for 4VWX5Y and 5Z, based on MARFIS, Jan. 31, 2013

Table 4: Condition of wolffish captured and released in NL commercial fisheries conducted in Canada's EEZ. Data are from SARA logbooks (updated to 14-Dec-2012; therefore, 2012 is incomplete).

Species	Condition	2004	2005	2006	2007	2008	2009	2010	2011	2012
Wolffish, Northern	Alive	22	307	560	347	330	594	788	555	344
	Dead	52	117	62	190	22	68	164	344	334
	% Alive	30%	72%	90%	65%	94%	90%	83%	62%	51%
Wolffish, Spotted	Alive	62	957	865	902	1039	1941	1842	1901	1038
	Dead	3	83	21	38	43	34	117	145	164
	% Alive	95%	92%	98%	96%	96%	98%	94%	93%	86%
Wolffish, Atlantic	Alive	.	121	114	258	231	343	331	195	183
	Dead	.	8	9	13	27	71	194	310	250
	% Alive	.	94%	93%	95%	90%	83%	63%	39%	42%

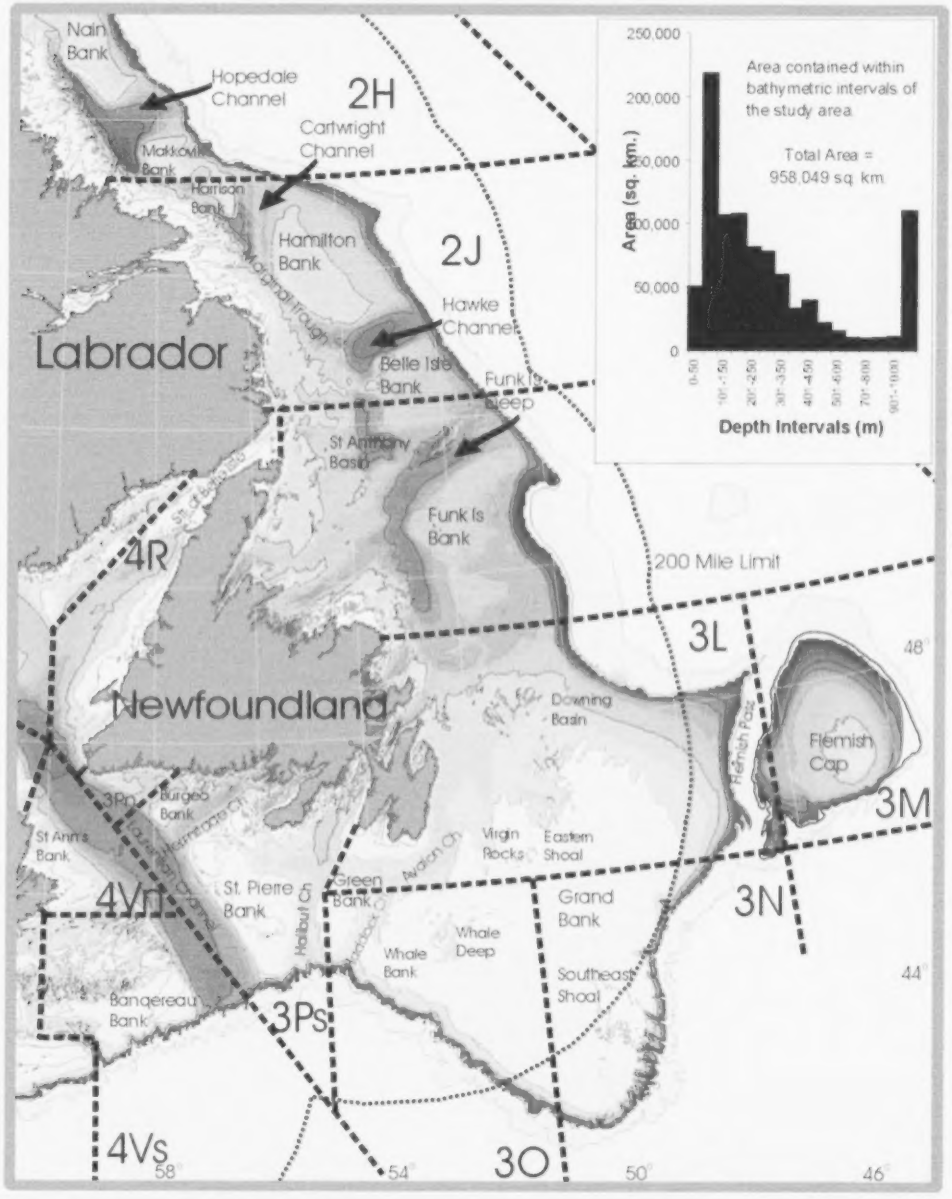


Figure 1. Map of the continental shelf off Eastern Canada and geographic features mentioned in the text. Depth range: <100 m (light grey) to >1000 m (dark grey). Canada's 200-Mile Limit is delineated by a thin dotted line, and NAFO Divisions by thick dotted lines.

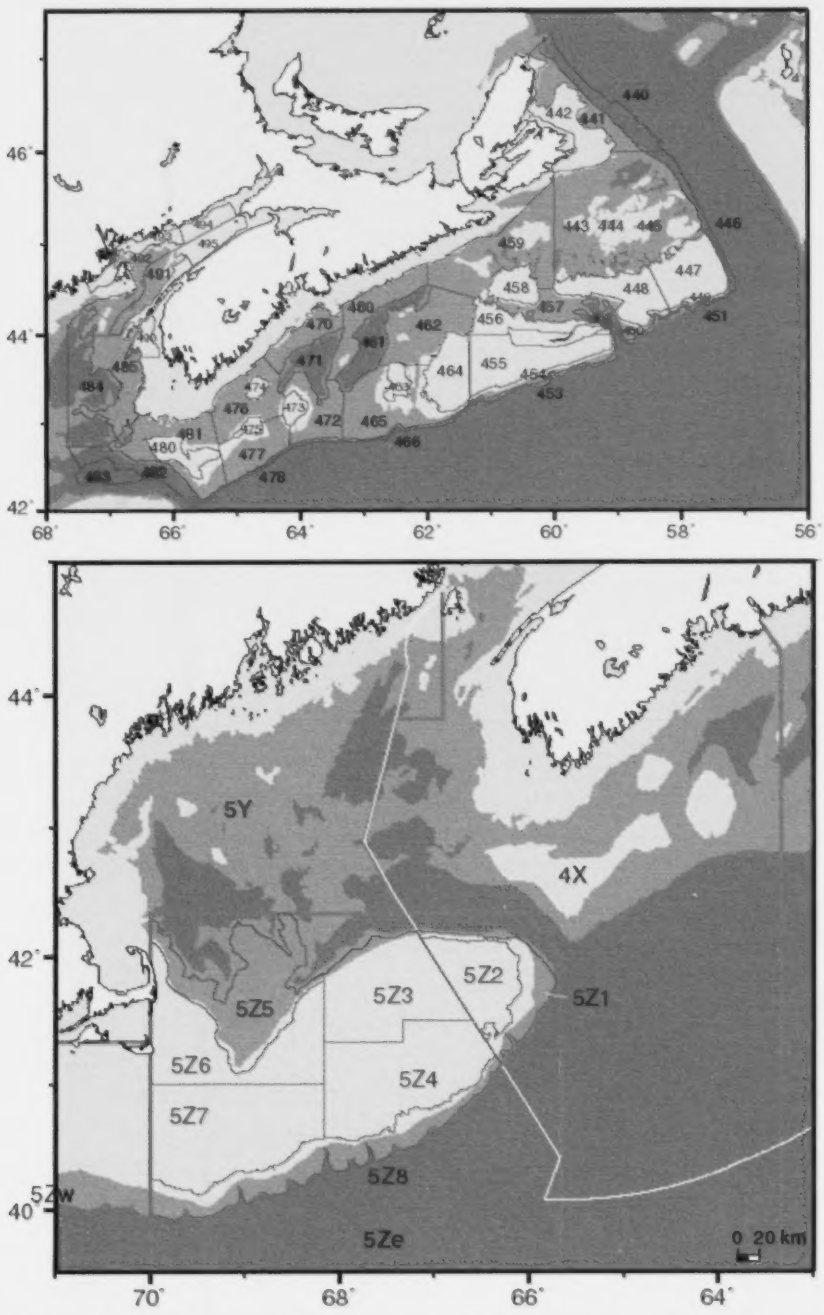


Figure 2. Strata used during the summer RV survey (top panel) and the Georges Bank RV survey (bottom panel). The deepwater strata, added to the summer RV survey in 1995, are not displayed.

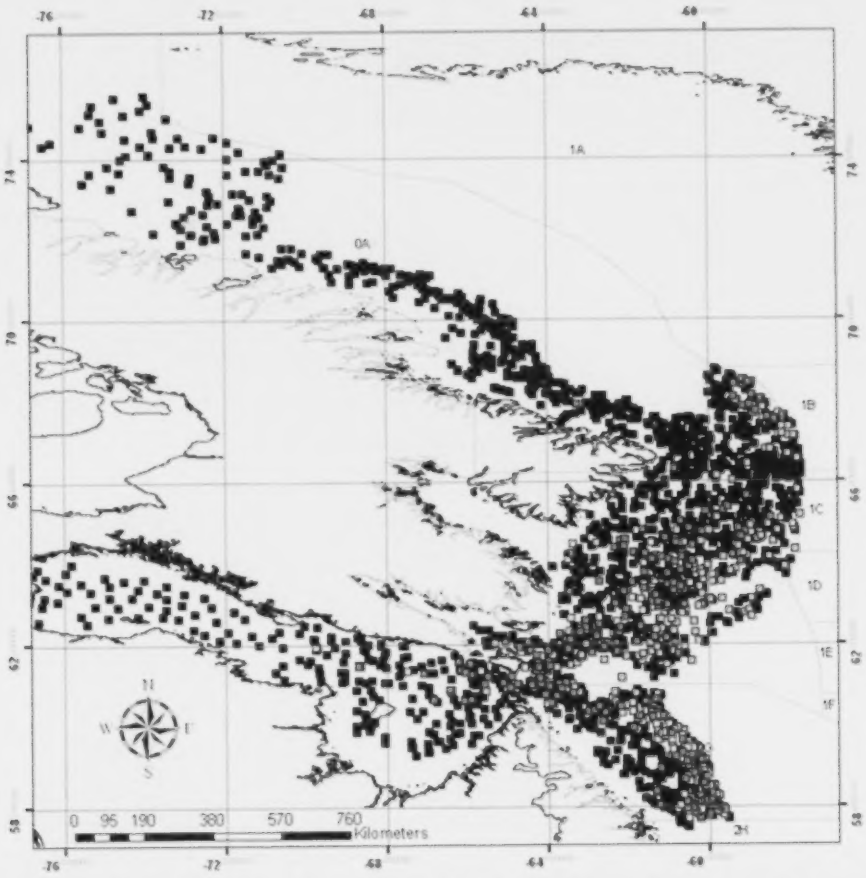


Figure 3. Locations of Northern (blue), Spotted (red), and Atlantic Wolffish (green) catches in research survey trawls (black squares indicate trawls without wolffish) in NAFO Subarea 0, Div. 2G, and Hudson Strait in 1978-2010.

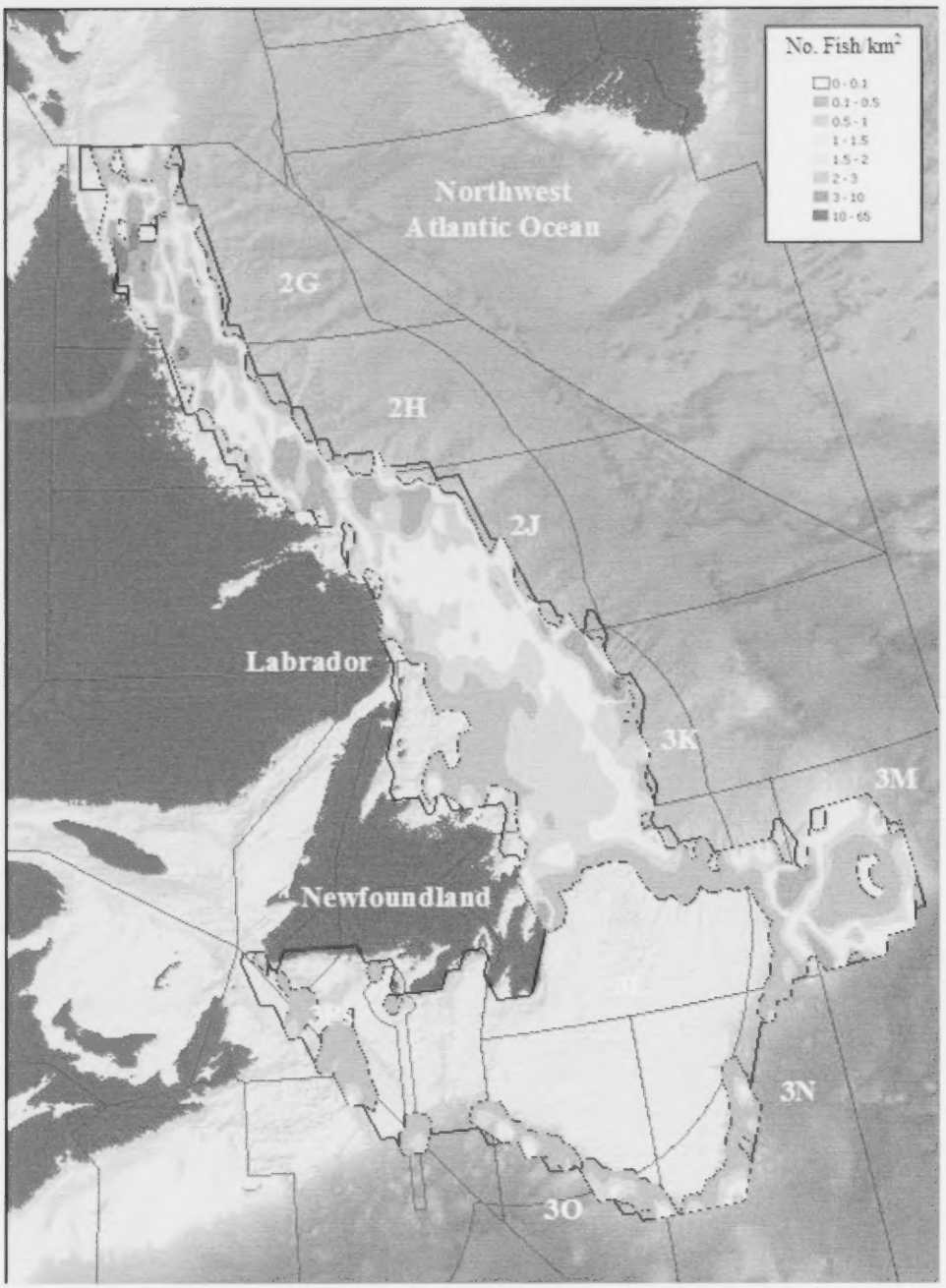


Figure 4a. Kernel density surface map of Northern Wolffish during the spring and fall surveys (1977-94).

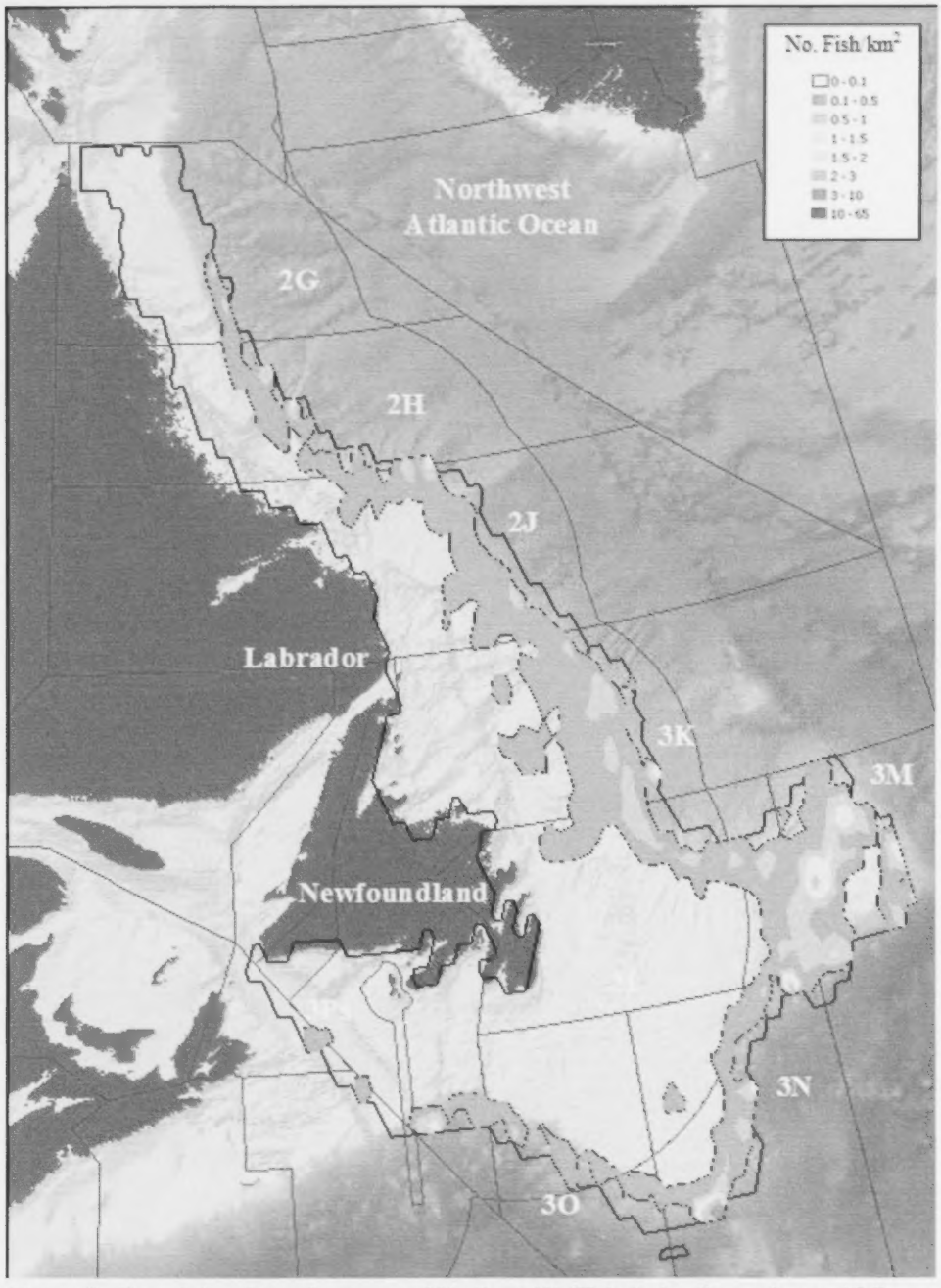


Figure 4b. Kernel density surface map of Northern Wolffish during the spring and fall surveys (1995-2012).

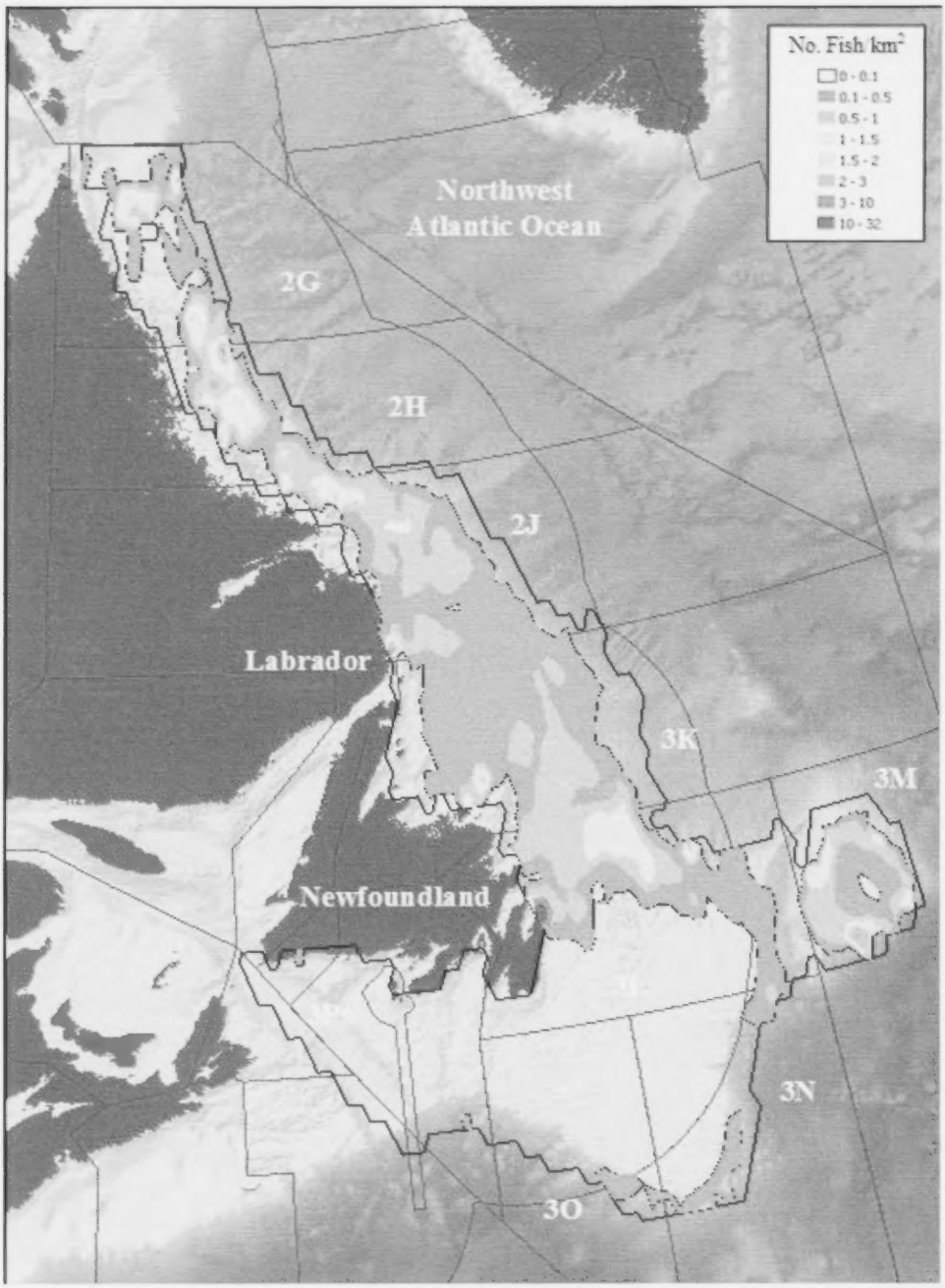


Figure 5a. Kernel density surface map of Spotted Wolffish during the spring and fall surveys (1977-94).

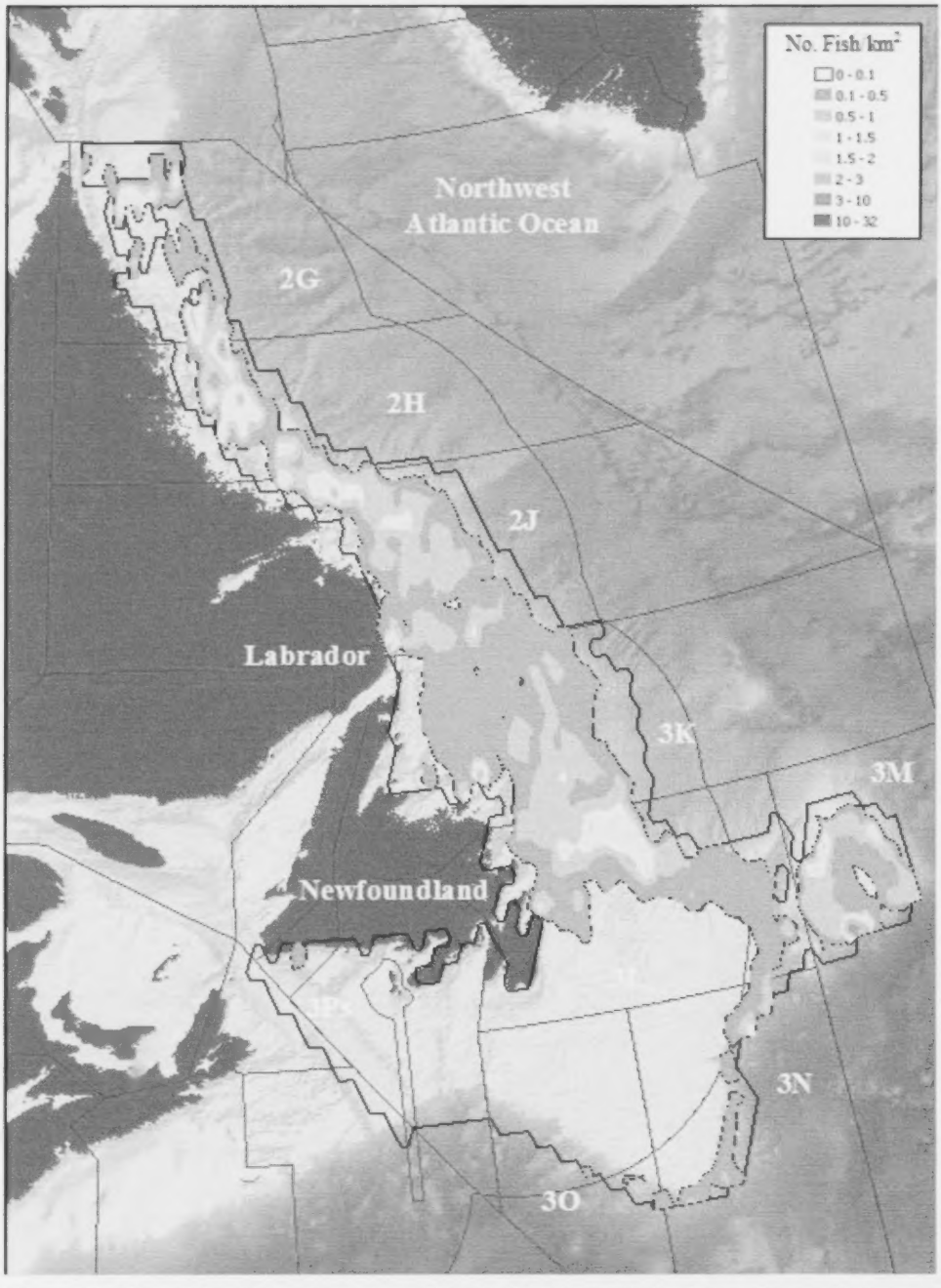


Figure 5b. Kernel density surface map of Spotted Wolffish during the spring and fall surveys (1995-2012).

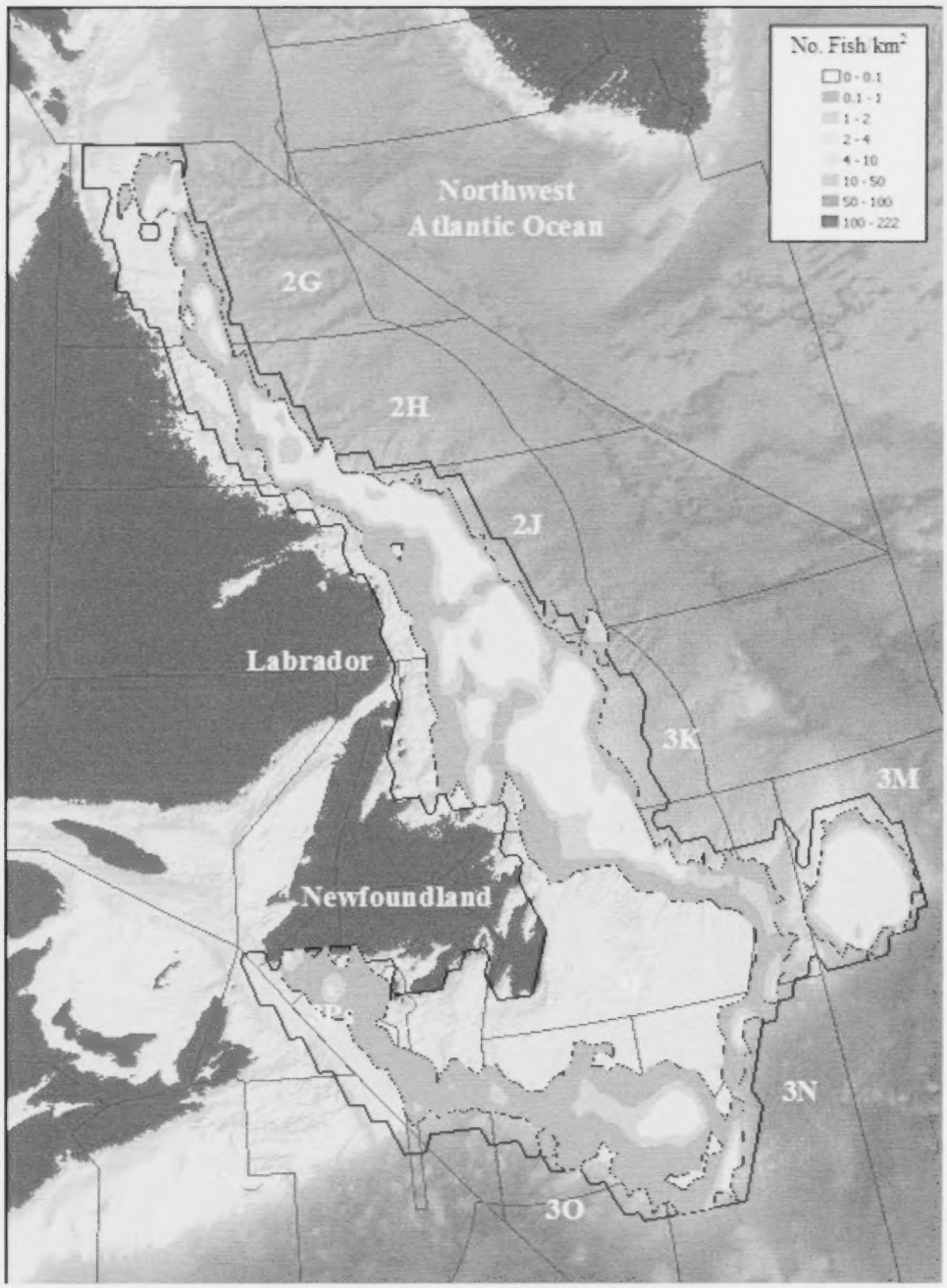


Figure 6a. Kernel density surface map of Atlantic Wolffish during the spring and fall surveys (1977-94).

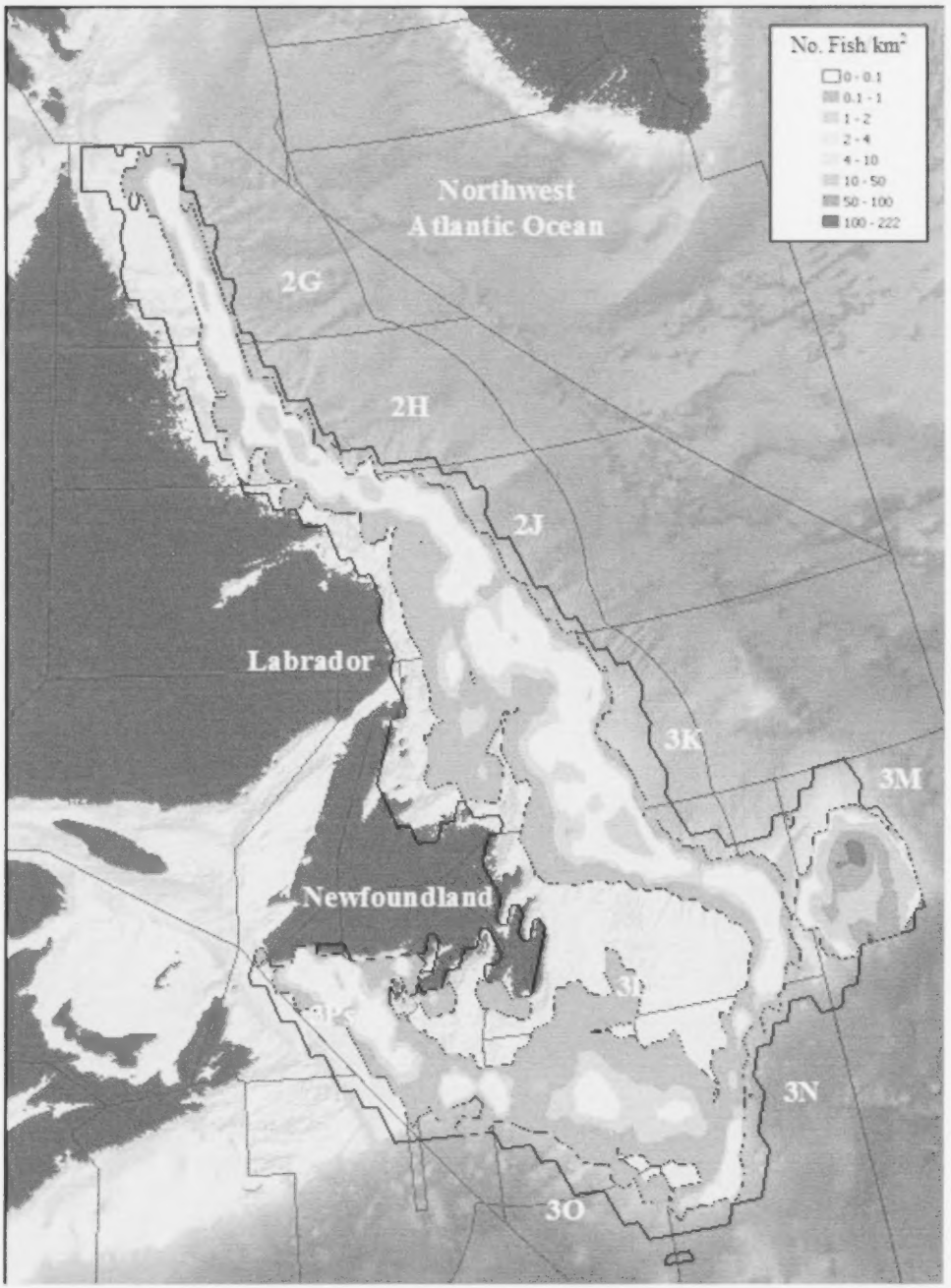


Figure 6b. Kernel density surface map of Atlantic Wolffish during the spring and fall surveys (1995-2012).

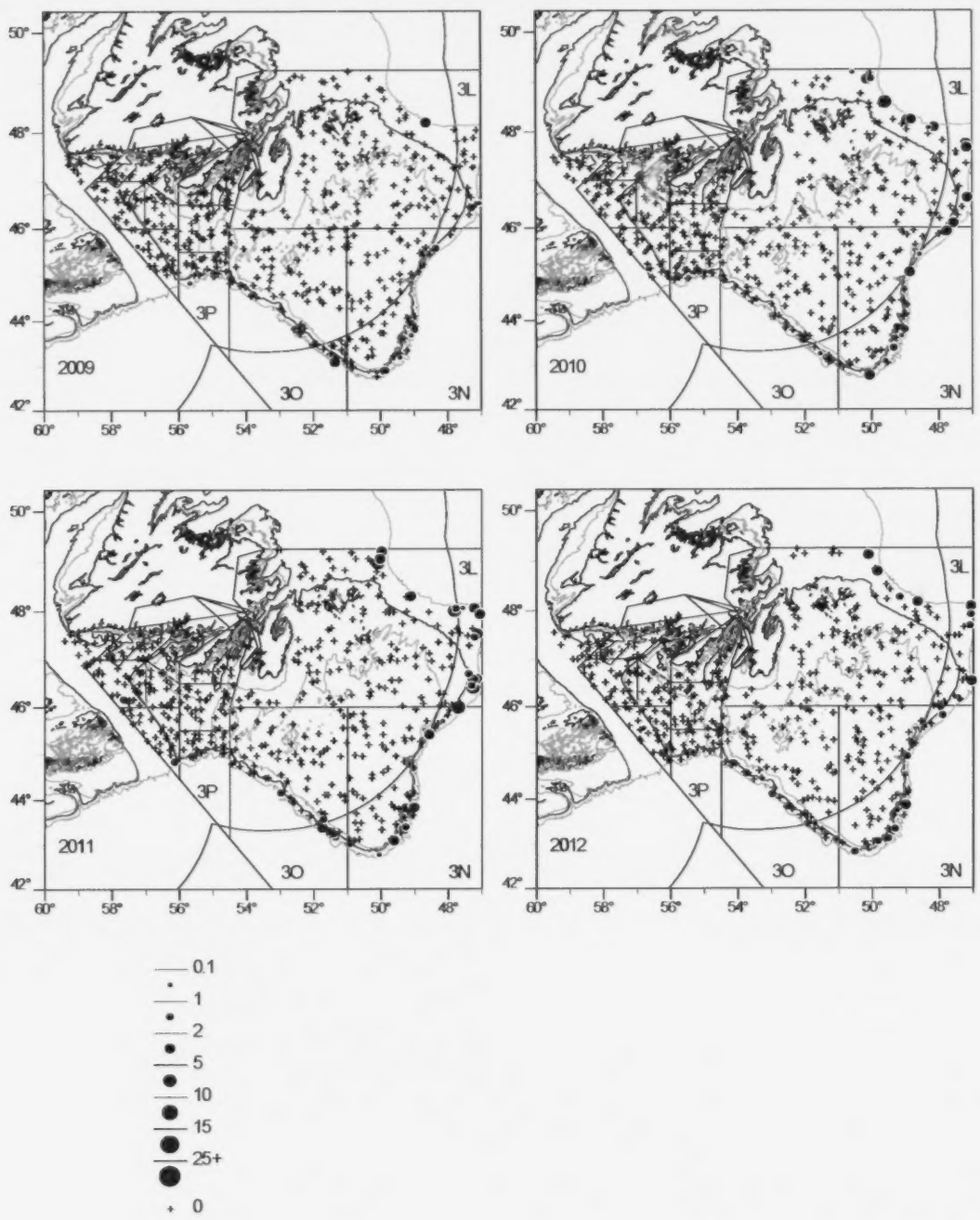


Figure 7. Distribution of recent catches of Northern Wolffish, based on Canadian spring research surveys in 2009 (Upper Left), 2010 (Upper Right), 2011 (Lower Left), and 2012 (Lower Right).

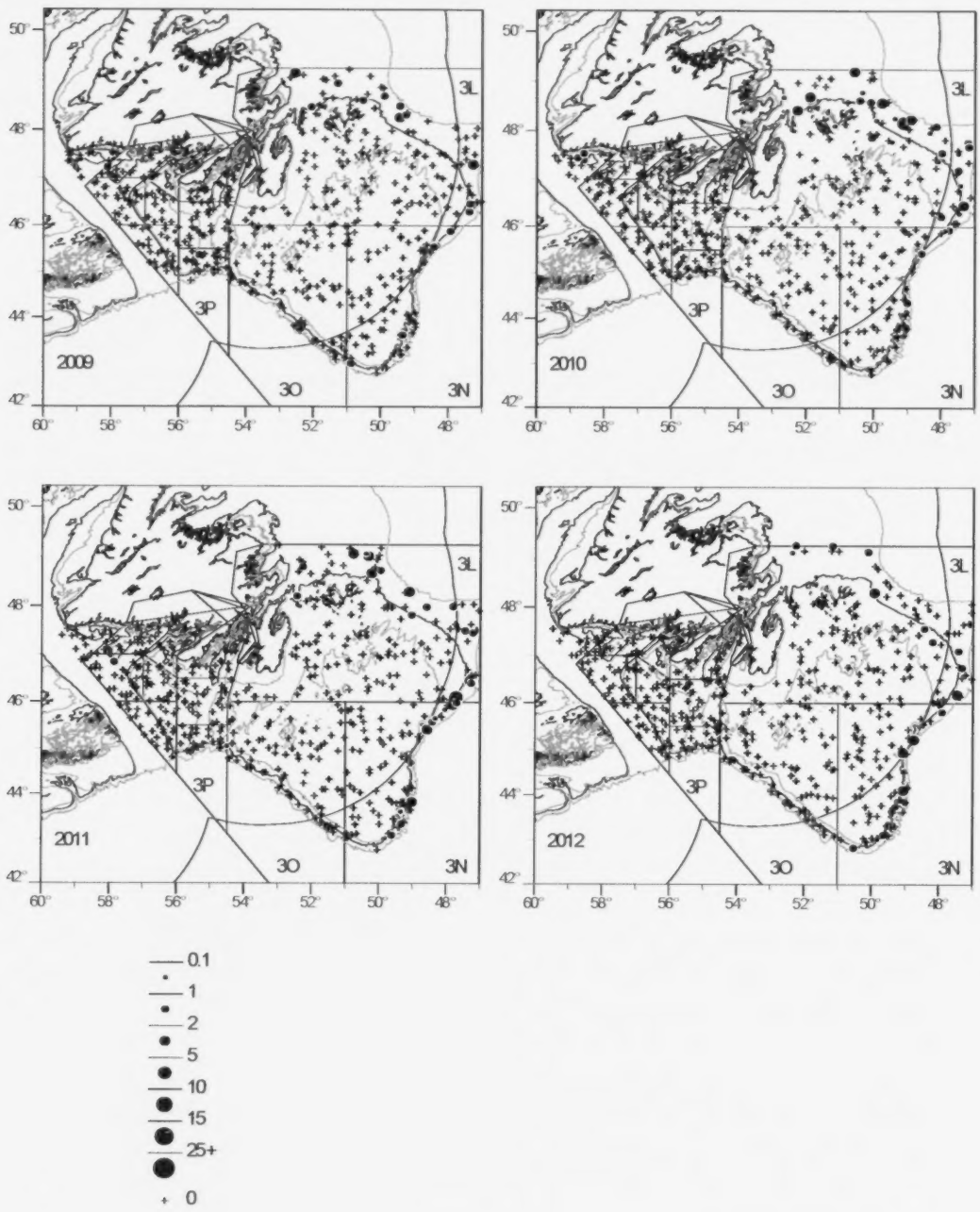


Figure 8. Distribution of recent catches of Spotted Wolffish, based on Canadian spring research surveys in 2009 (Upper Left), 2010 (Upper Right), 2011 (Lower Left), and 2012 (Lower Right).

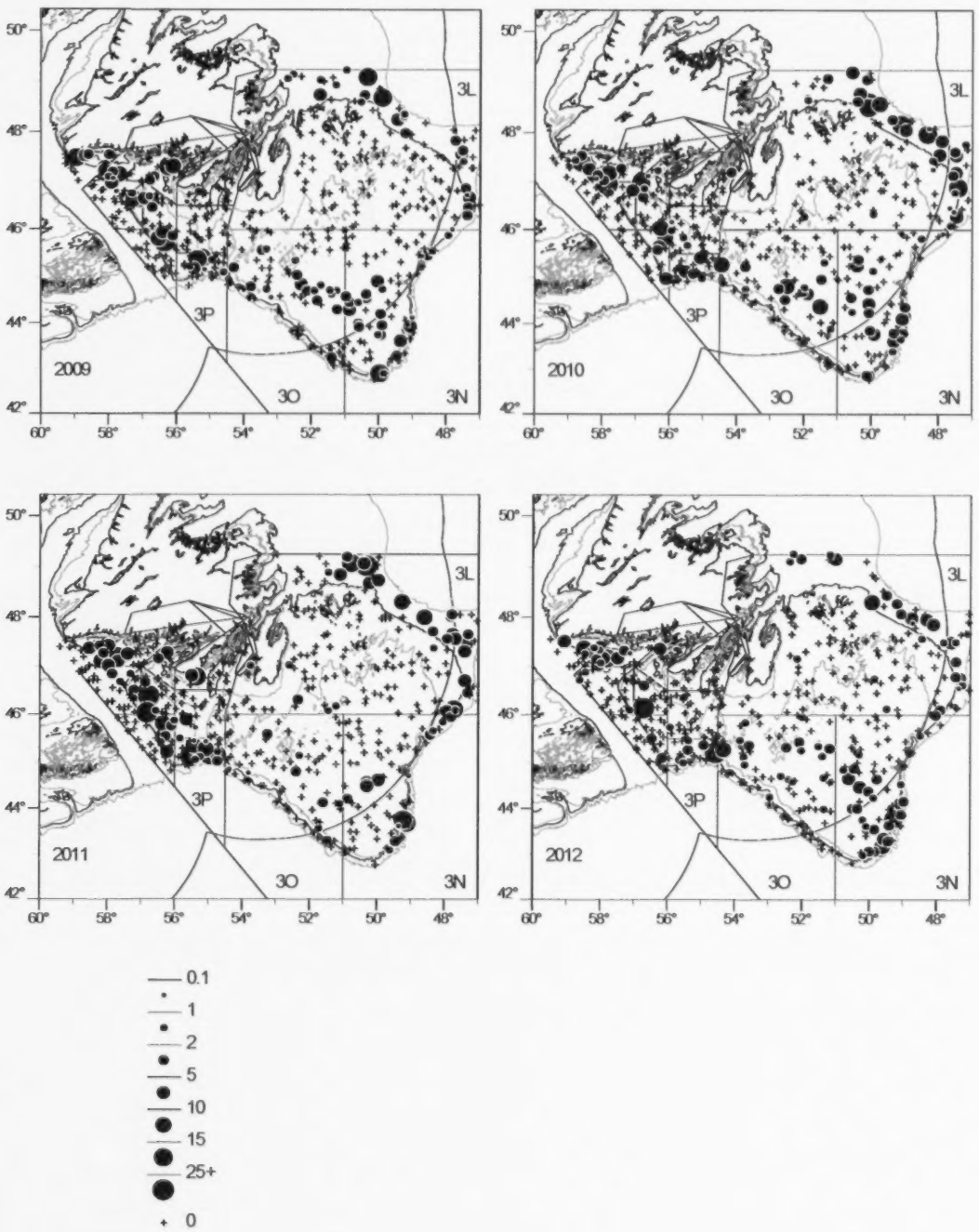


Figure 9. Distribution of recent catches of Atlantic Wolffish, based on Canadian spring research surveys in 2009 (Upper Left), 2010 (Upper Right), 2011 (Lower Left), and 2012 (Lower Right).

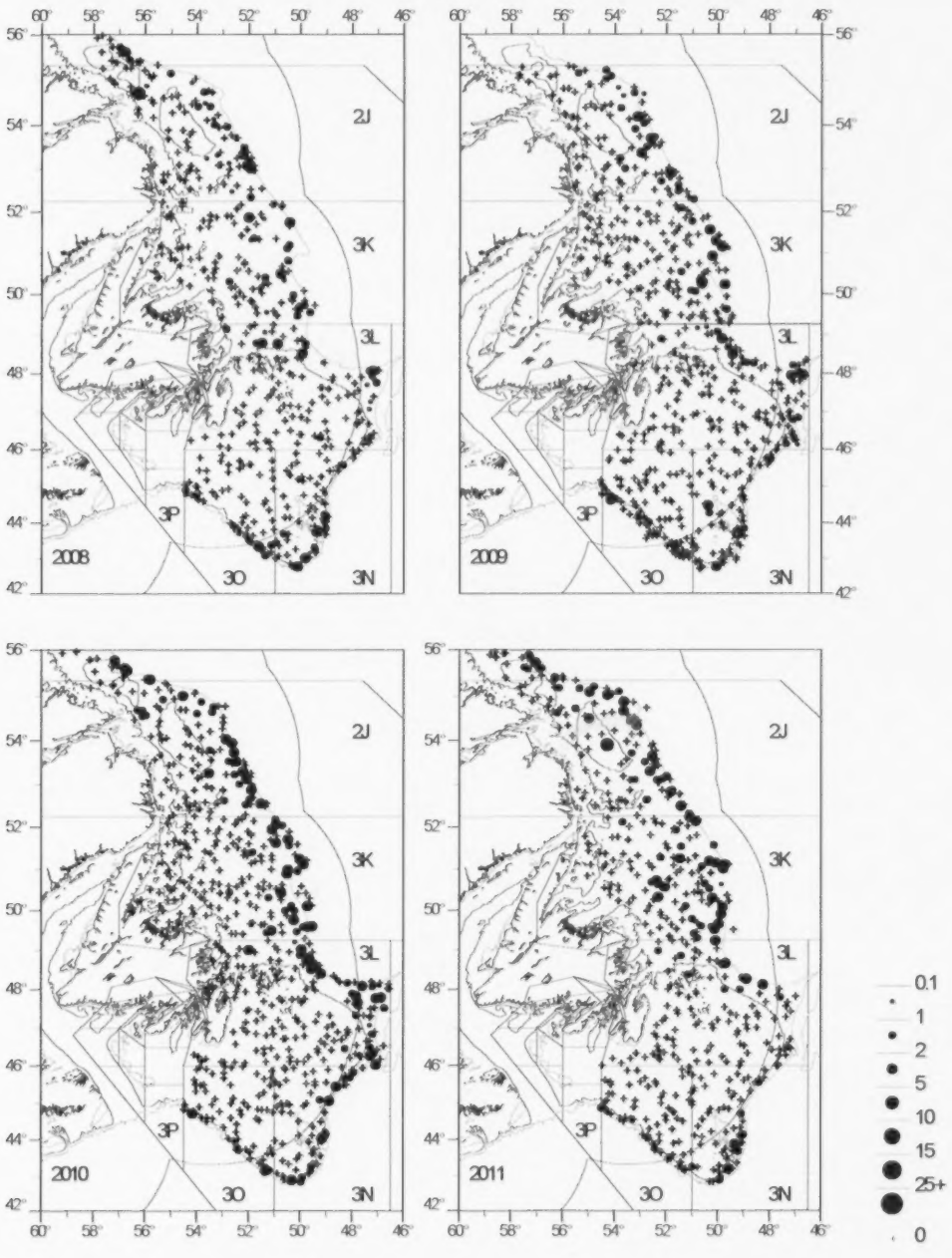


Figure 10. Distribution of recent catches of Northern Wolffish, based on Canadian fall research surveys in 2008 (Upper Left), 2009 (Upper Right), 2010 (Lower Left), and 2011 (Lower Right).

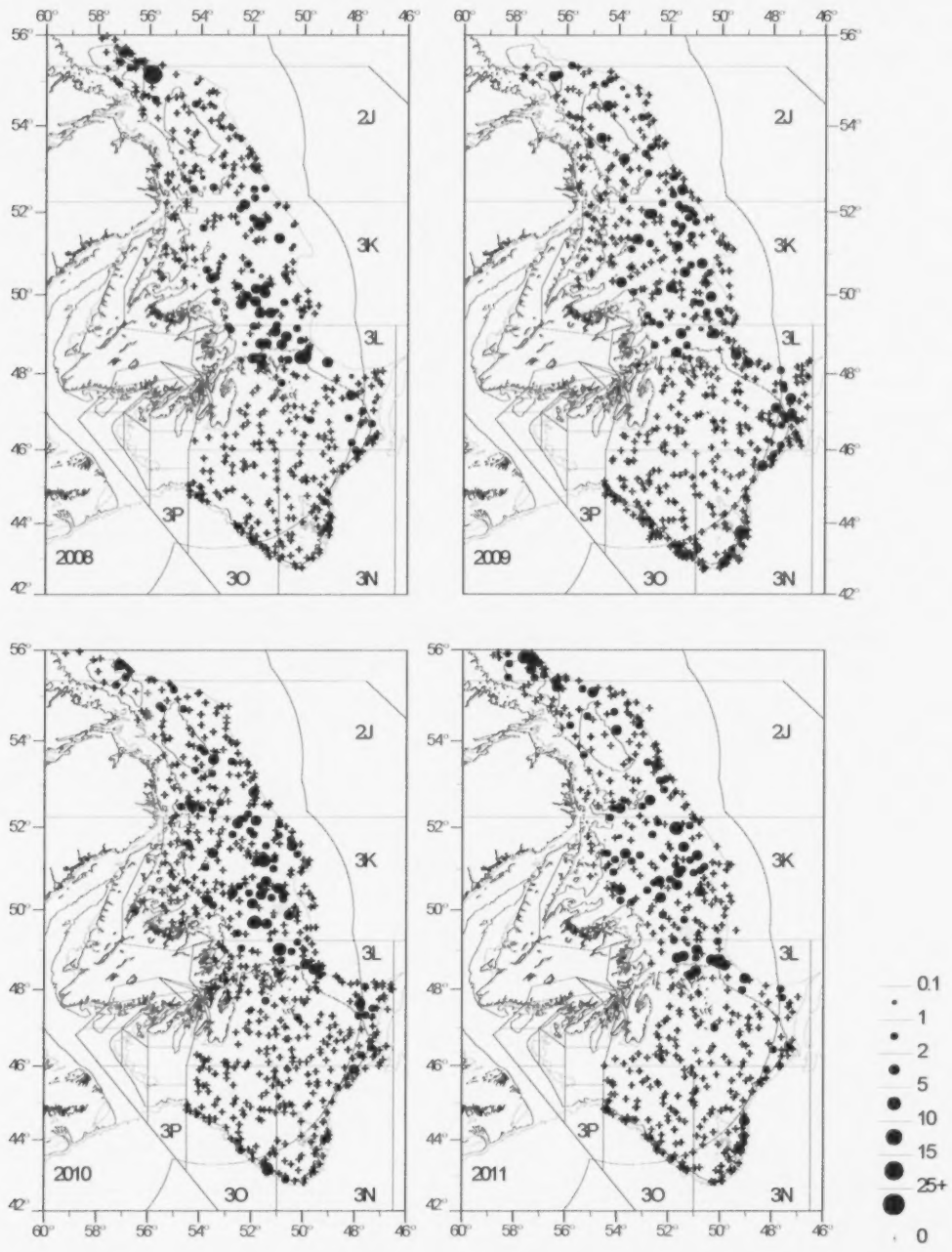


Figure 11. Distribution of recent catches of Spotted Wolffish, based on Canadian fall research surveys in 2008 (Upper Left), 2009 (Upper Right), 2010 (Lower Left), and 2011 (Lower Right).

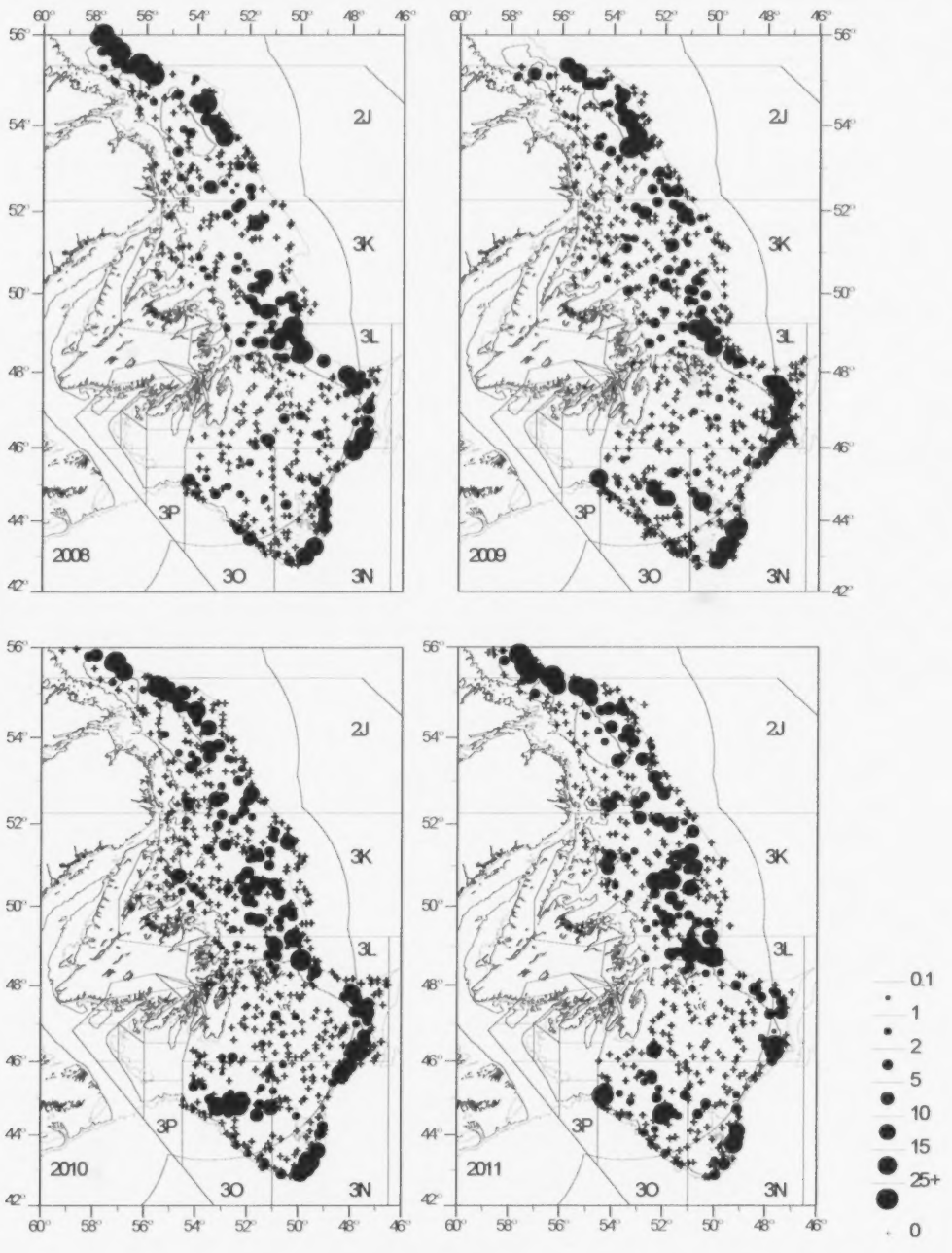


Figure 12. Distribution of recent catches of Atlantic Wolffish, based on Canadian fall research surveys in 2008 (Upper Left), 2009 (Upper Right), 2010 (Lower Left), and 2011 (Lower Right).

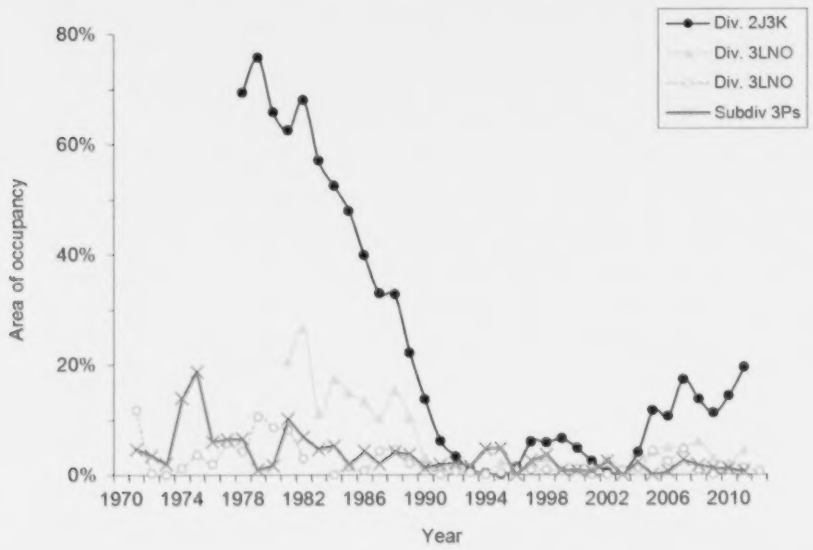


Figure 13. Area of occupancy for Northern Wolffish in Div. 2J3K , Subdiv. 3Ps, and Div.3LNO in spring (1971-2012; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

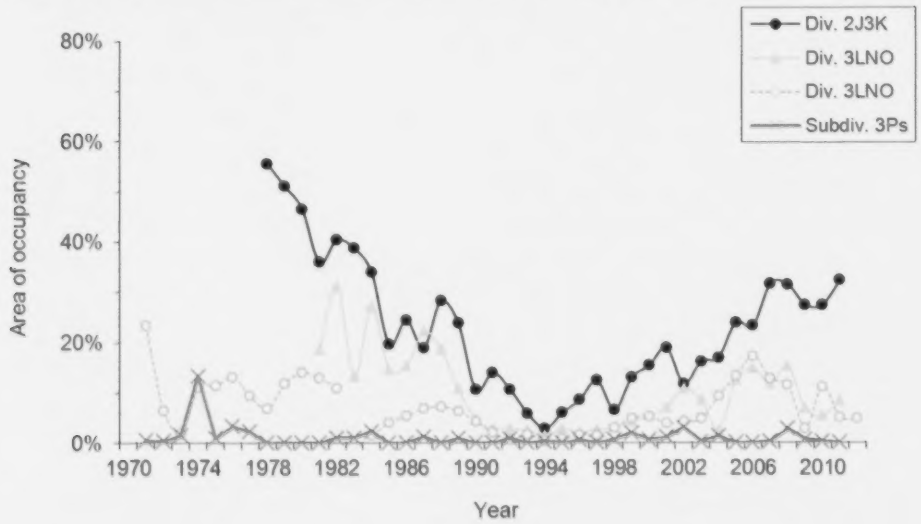


Figure 14. Area of occupancy for Spotted Wolffish in Div. 2J3K, Subdiv. 3Ps, and Div.3LNO in spring (1971-2012; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

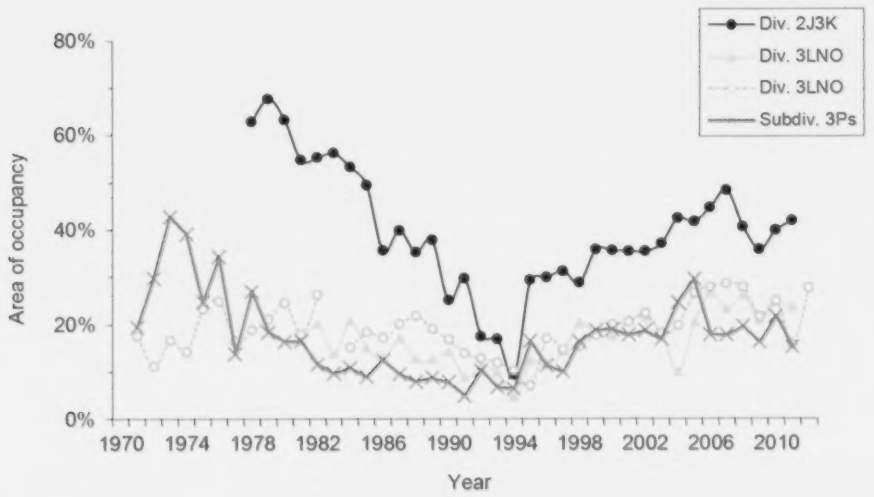


Figure 15. Area of occupancy for Atlantic Wolffish in Div. 2J3K, Subdiv. 3Ps, and Div.3LNO in spring (1971-2012; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

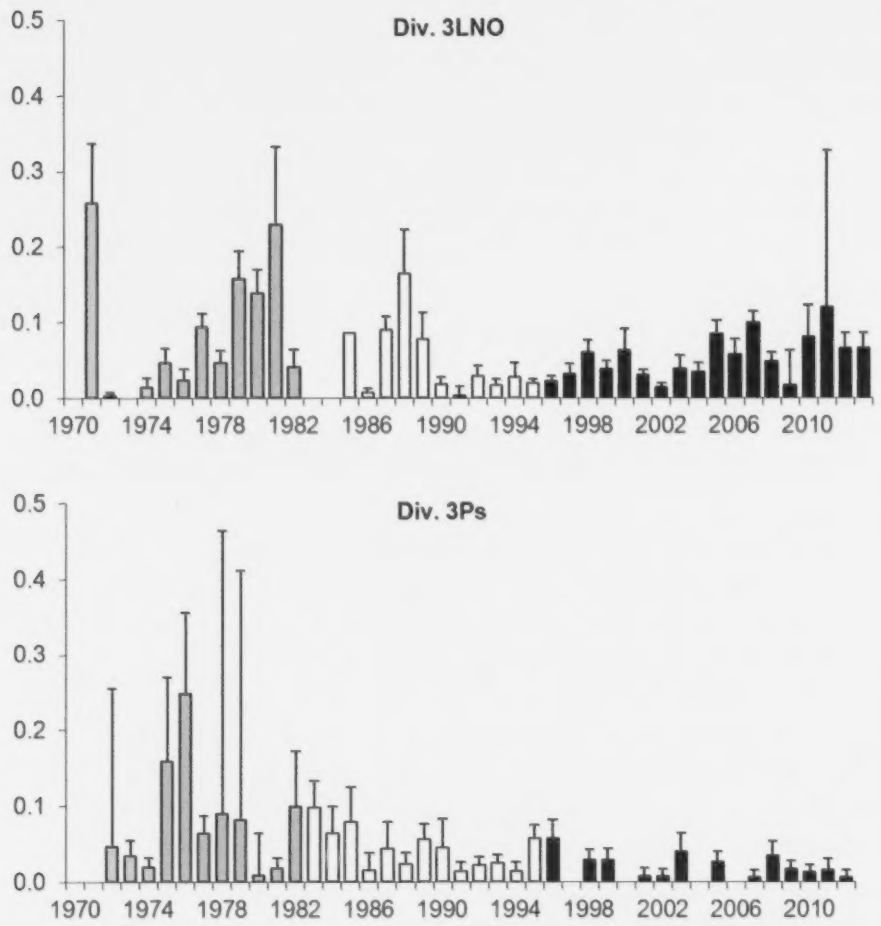


Figure 16a. Research survey indices for Northern Wolffish in Div. 3LNO and Subdiv. 3Ps in spring. T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in spring 1996.

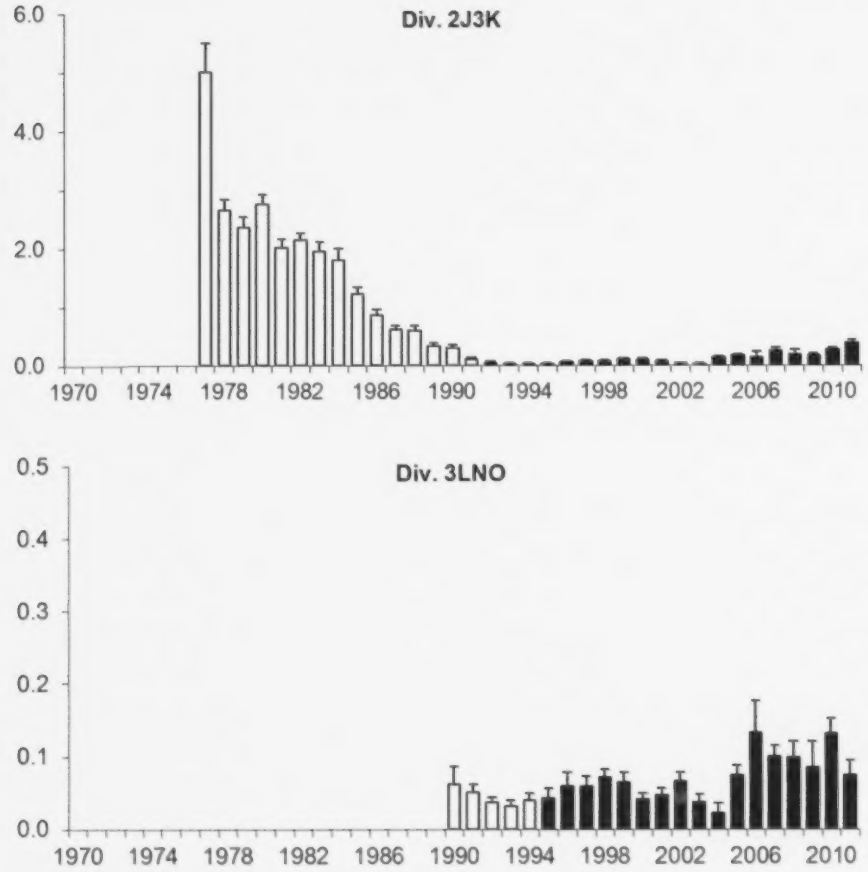


Figure 16b. Research survey indices for Northern Wolffish in Div.2J3K and Div. 3LNO in fall. T-bar = 1 SE. Survey trawl gear changed from Engel (white bar) to Campelen (black bar) in fall 1995.

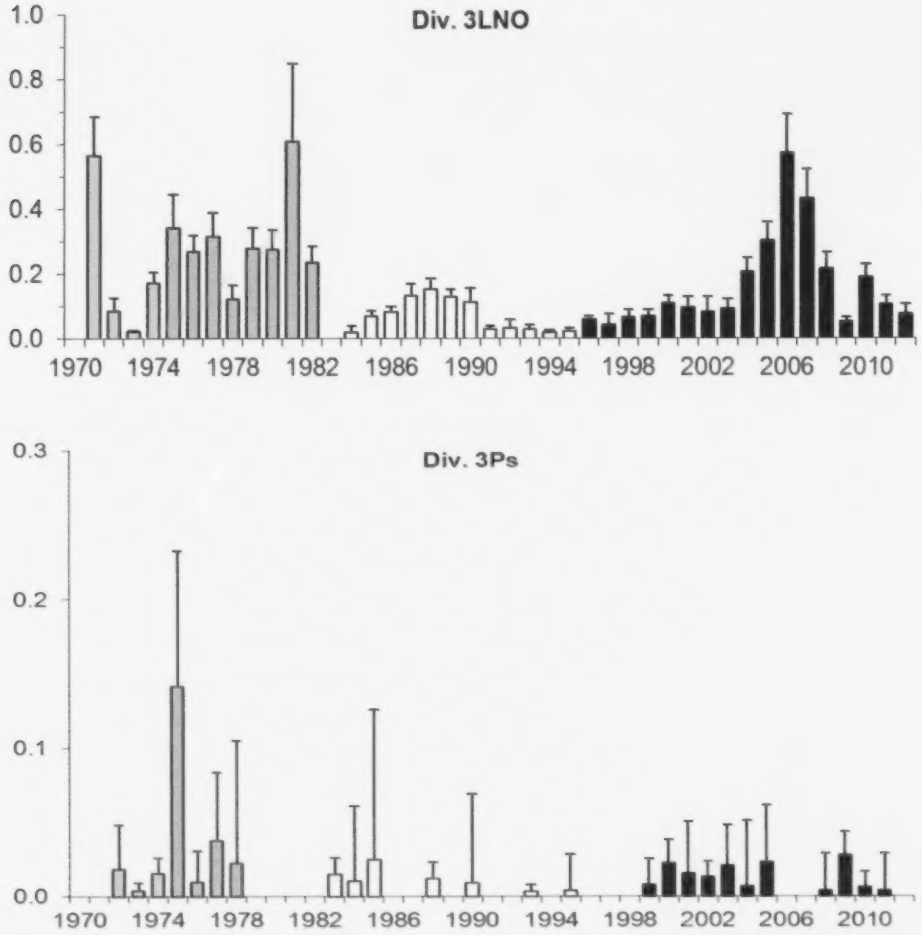


Figure 17a. Research survey indices for Spotted Wolffish in Div. 3LNO and Subdiv. 3Ps in spring. T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in spring 1996.

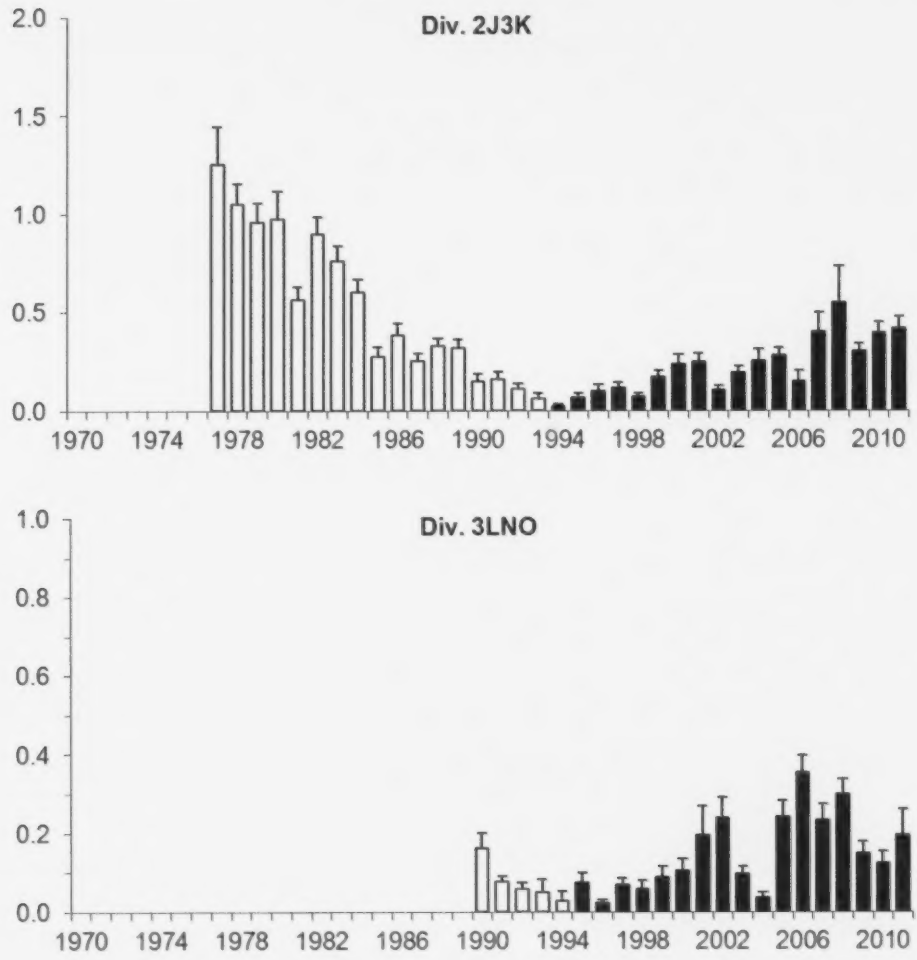


Figure 17b. Research survey indices for Spotted Wolffish in Div.2J3K and Div. 3LNO in fall. T-bar = 1 SE. Survey trawl gear changed from Engel (white bar) to Campelen (black bar) in fall 1995.

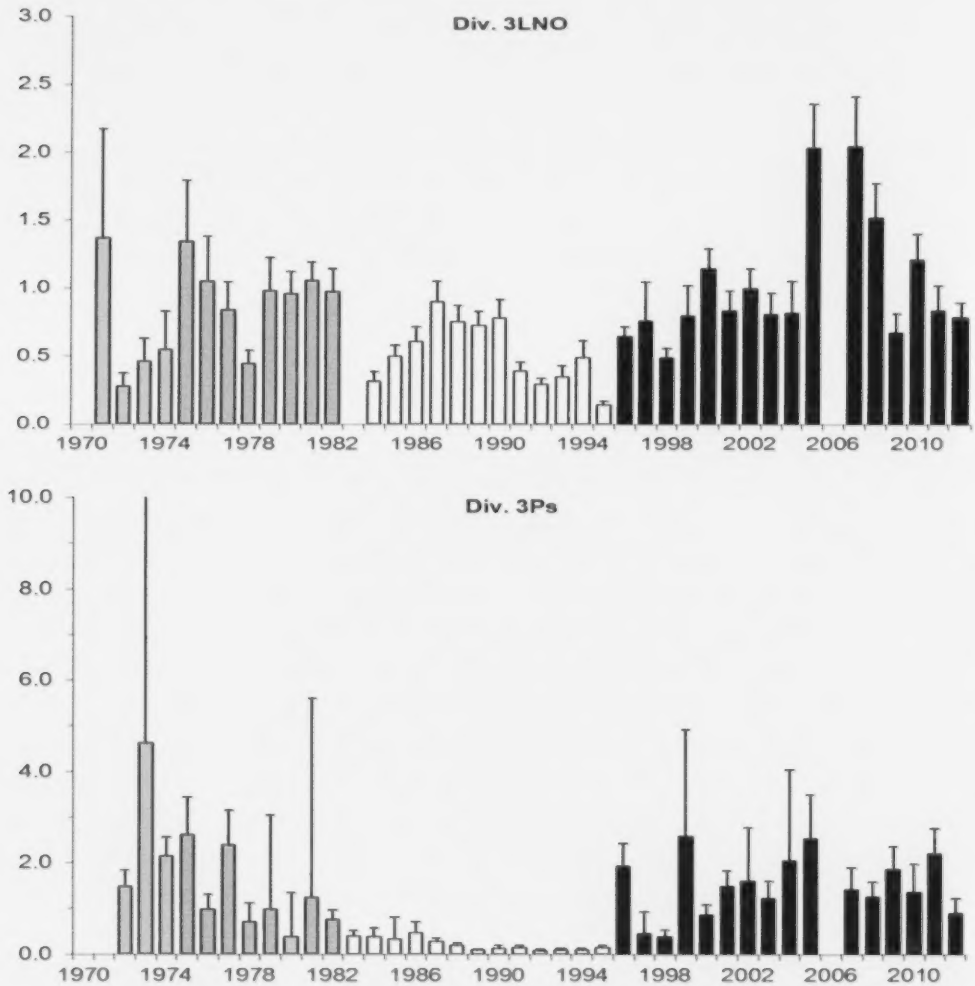


Figure 18a. Research survey indices for Atlantic Wolffish in Div. 3LNO and Subdiv. 3Ps in spring. T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in spring 1996.

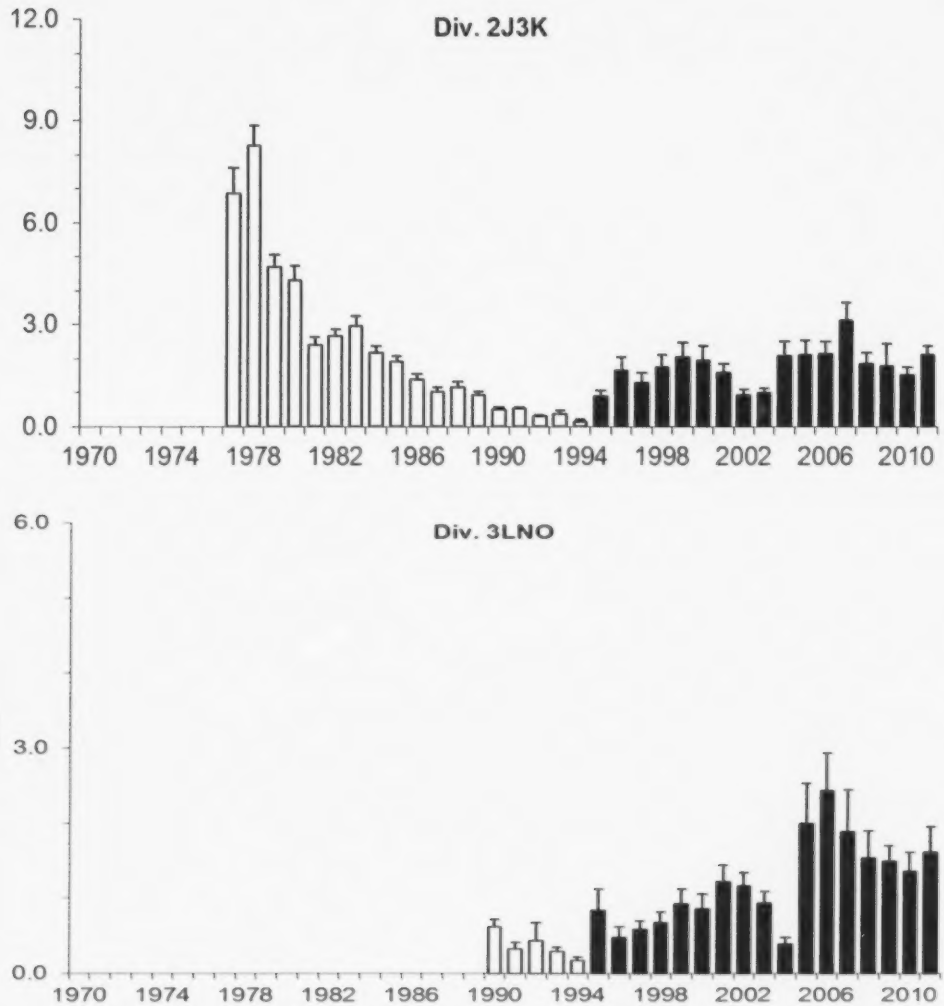


Figure 18b. Research survey indices for Atlantic Wolffish in Div.2J3K and Div. 3LNO in fall. T-bar = 1 SE. Survey trawl gear changed from Engel (white bar) to Campelen (black bar) in fall 1995.

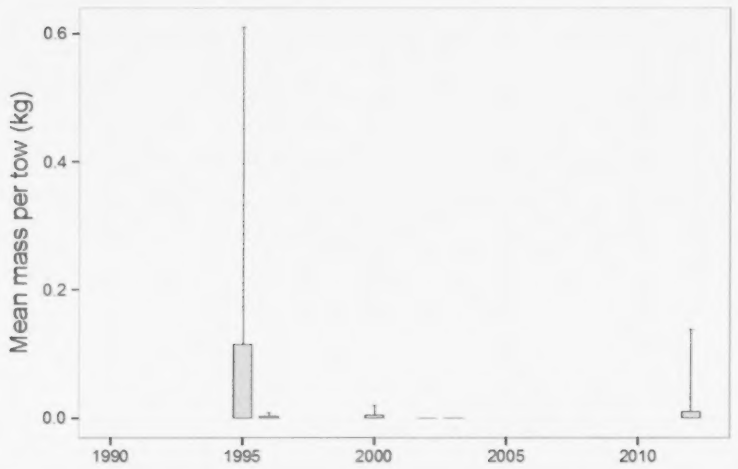


Figure 19. Abundance indices (average mass per tow) for Northern Wolffish in Div. 4RS (northern Gulf of St. Lawrence) during summer research surveys. Error bars are upper 95% confidence intervals.

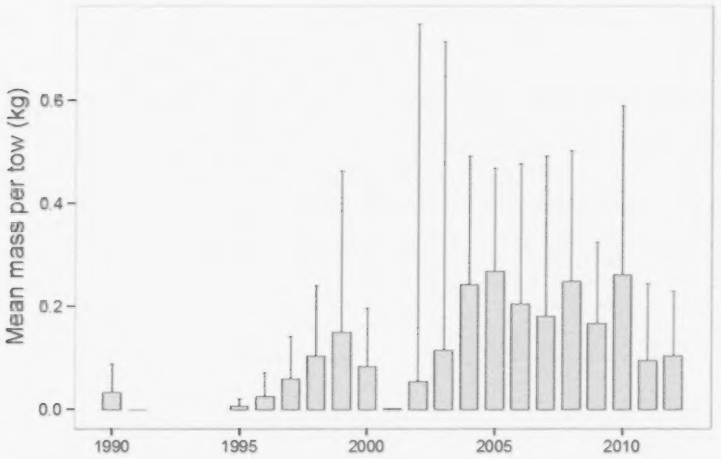


Figure 20. Abundance indices (average mass per tow) for Spotted Wolffish in Div. 4RS (northern Gulf of St. Lawrence) during summer research surveys. Error bars are upper 95% confidence intervals.

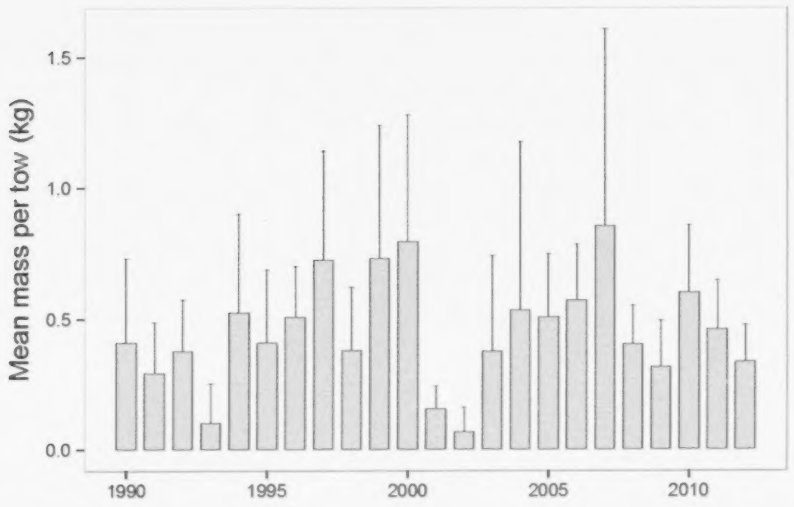


Figure 21. Abundance indices (average mass per tow) for Atlantic Wolffish in Div. 4RS (northern Gulf of St. Lawrence) during summer research surveys. Error bars are upper 95% confidence intervals.

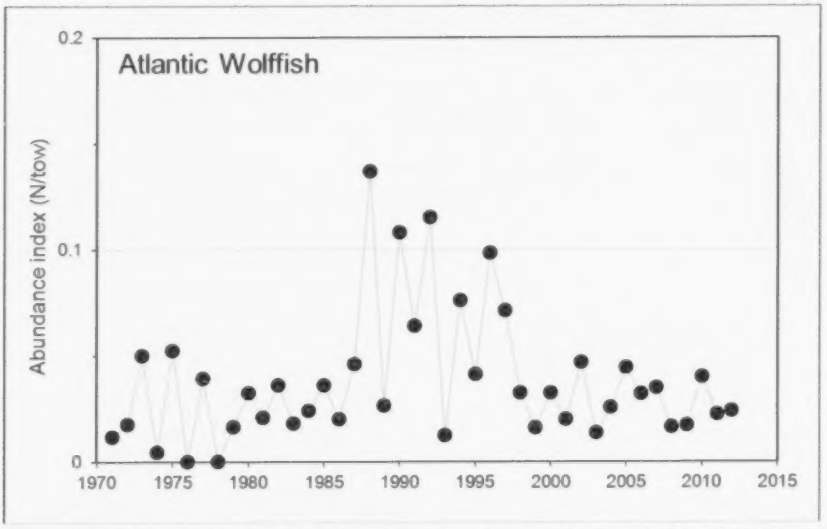


Figure 22. Abundance indices (average number per tow) for Atlantic Wolffish in Div. 4T (southern GSL; excluding the Estuary).

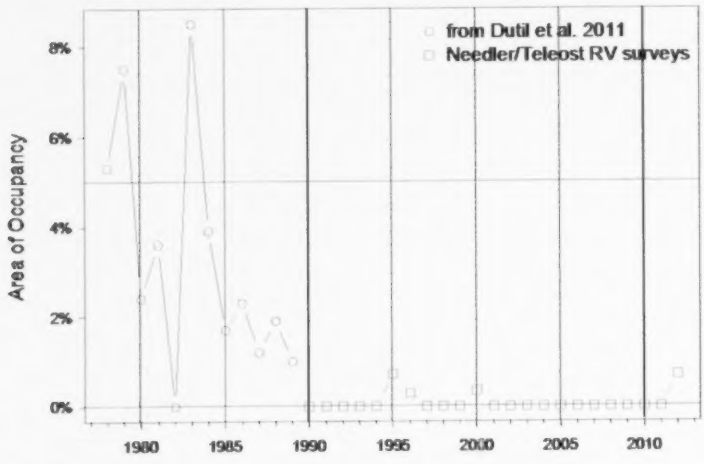


Figure 23. Area of occupancy for Northern Wolffish in Div. 4RS (northern Gulf of St. Lawrence).

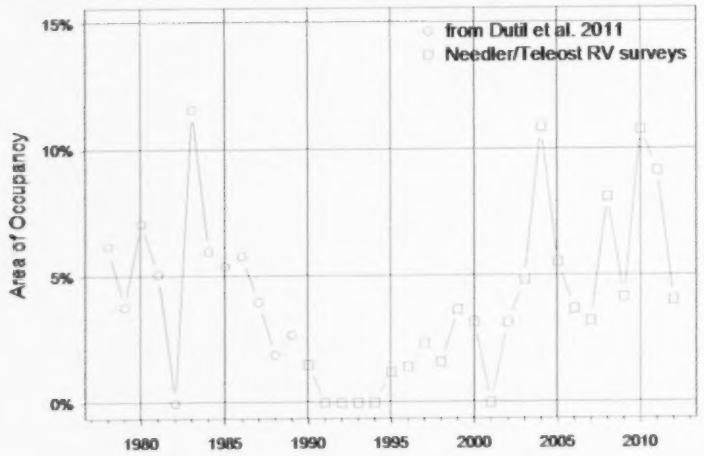


Figure 24. Area of occupancy for Spotted Wolffish in Div. 4RS (northern Gulf of St. Lawrence).

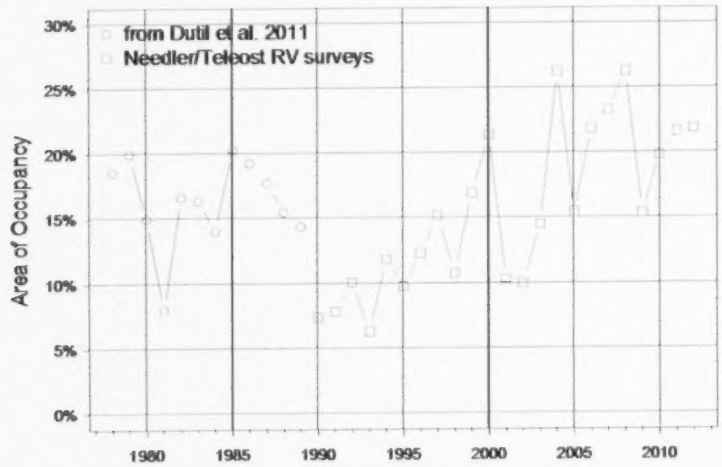


Figure 25. Area of occupancy for Atlantic Wolffish in Div. 4RS (northern Gulf of St. Lawrence).

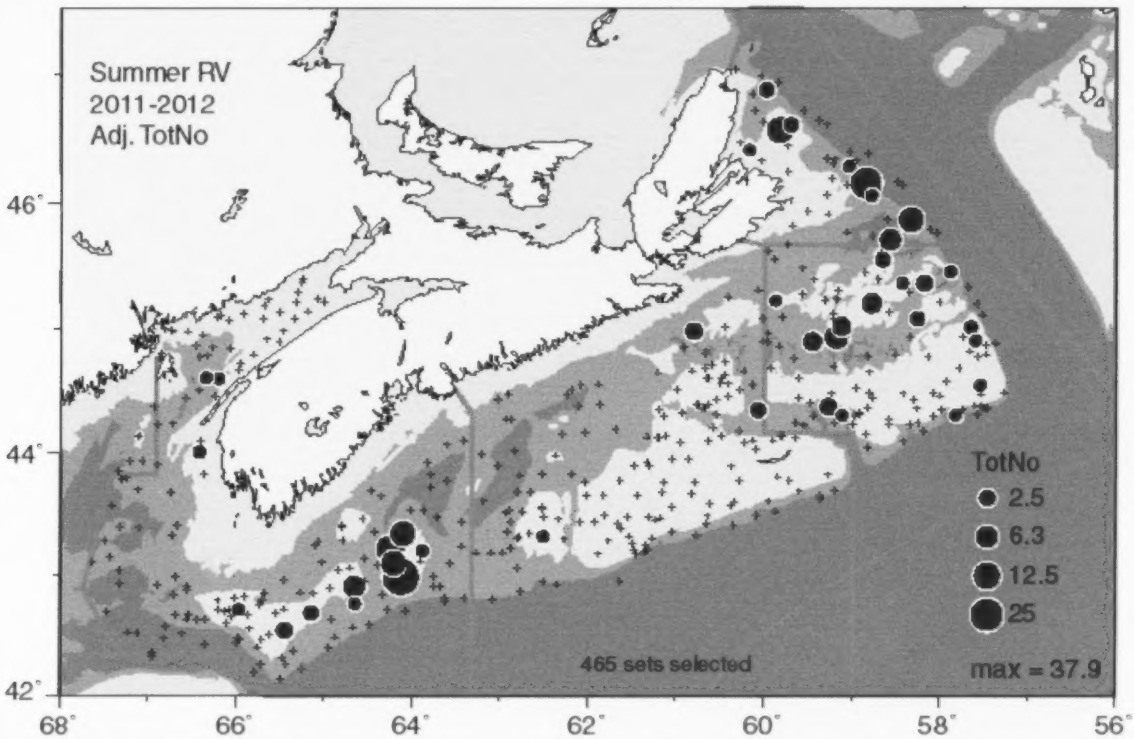
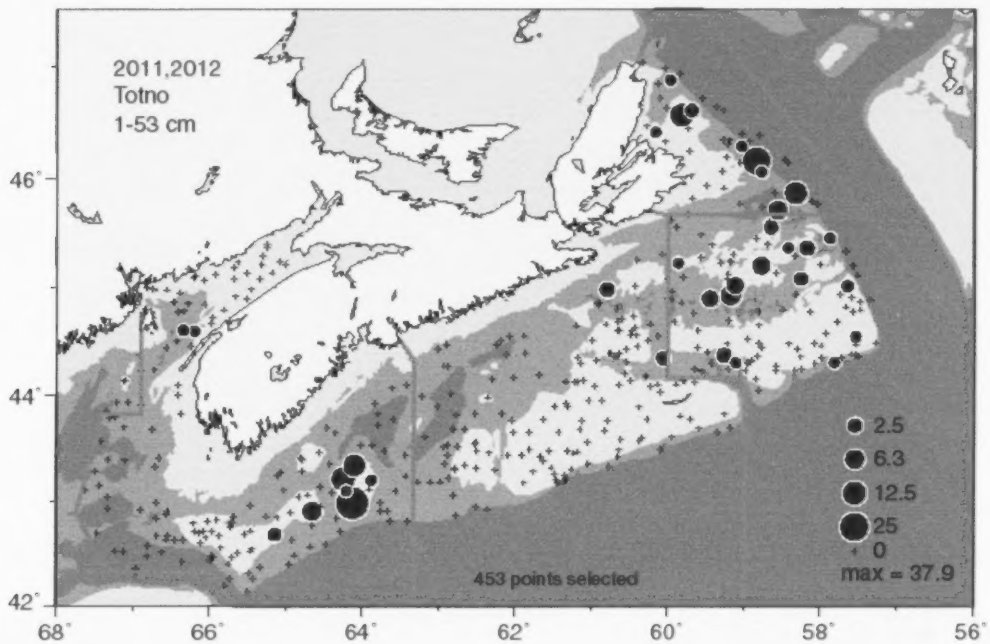


Figure 26. Distribution of Atlantic Wolffish as indicated by the Summer RV survey on the Scotian Shelf, 2011-12.



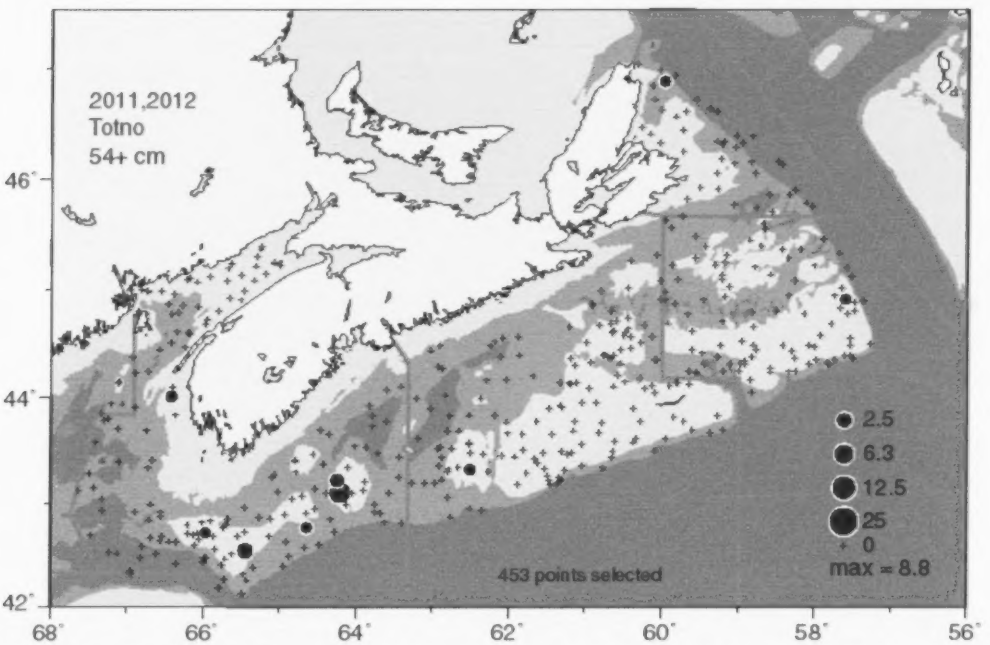


Figure 27. Distribution of immature (1-53 cm) and mature (>53 cm) Atlantic Wolffish as indicated by the summer RV surveys in 2011 and 2012. This figure does not include the deep water sets on the edge of the Scotian Shelf.

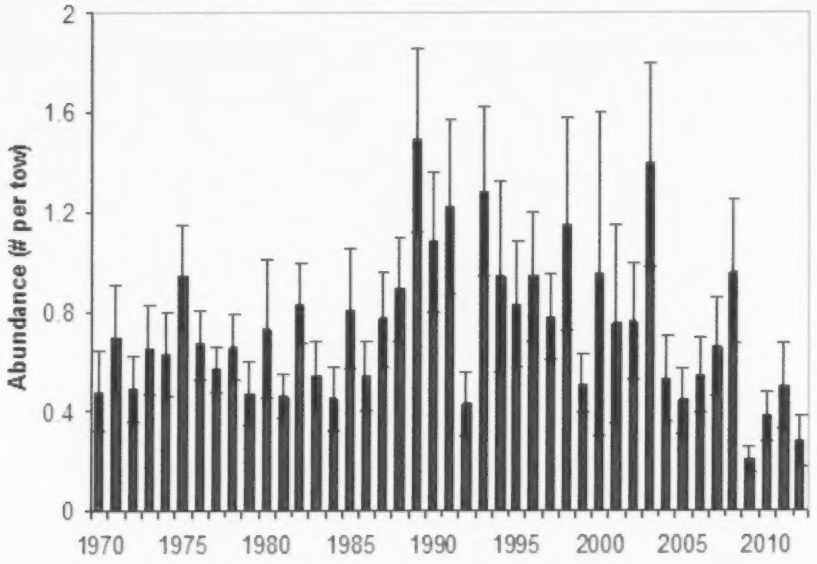


Figure 28. Abundance indices (number per tow) for Atlantic Wolffish (all lengths) in Div. 4VWX (and a small area of Div. 5Y) during summer research surveys, 1970-2012.

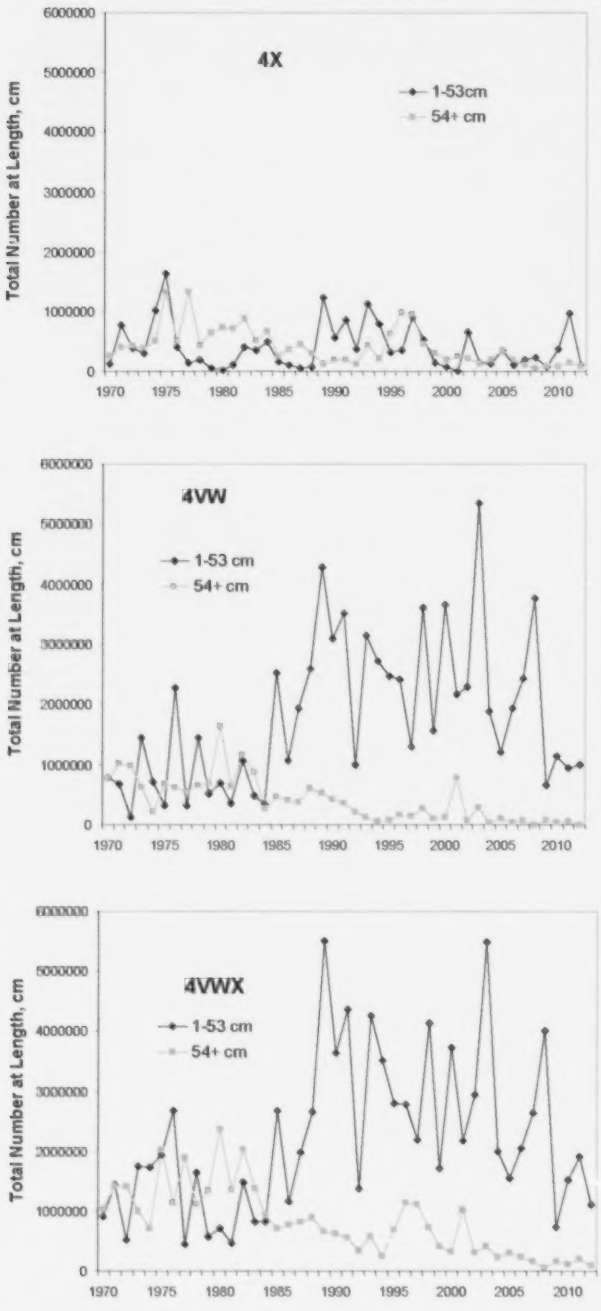


Figure 29. Abundance of immature (1-53 cm) and mature (>53 cm) of Atlantic Wolffish caught during the summer RV survey, from Div. 4X, Div. 4VW, and Div. 4VWX., from 1970 to 2012.

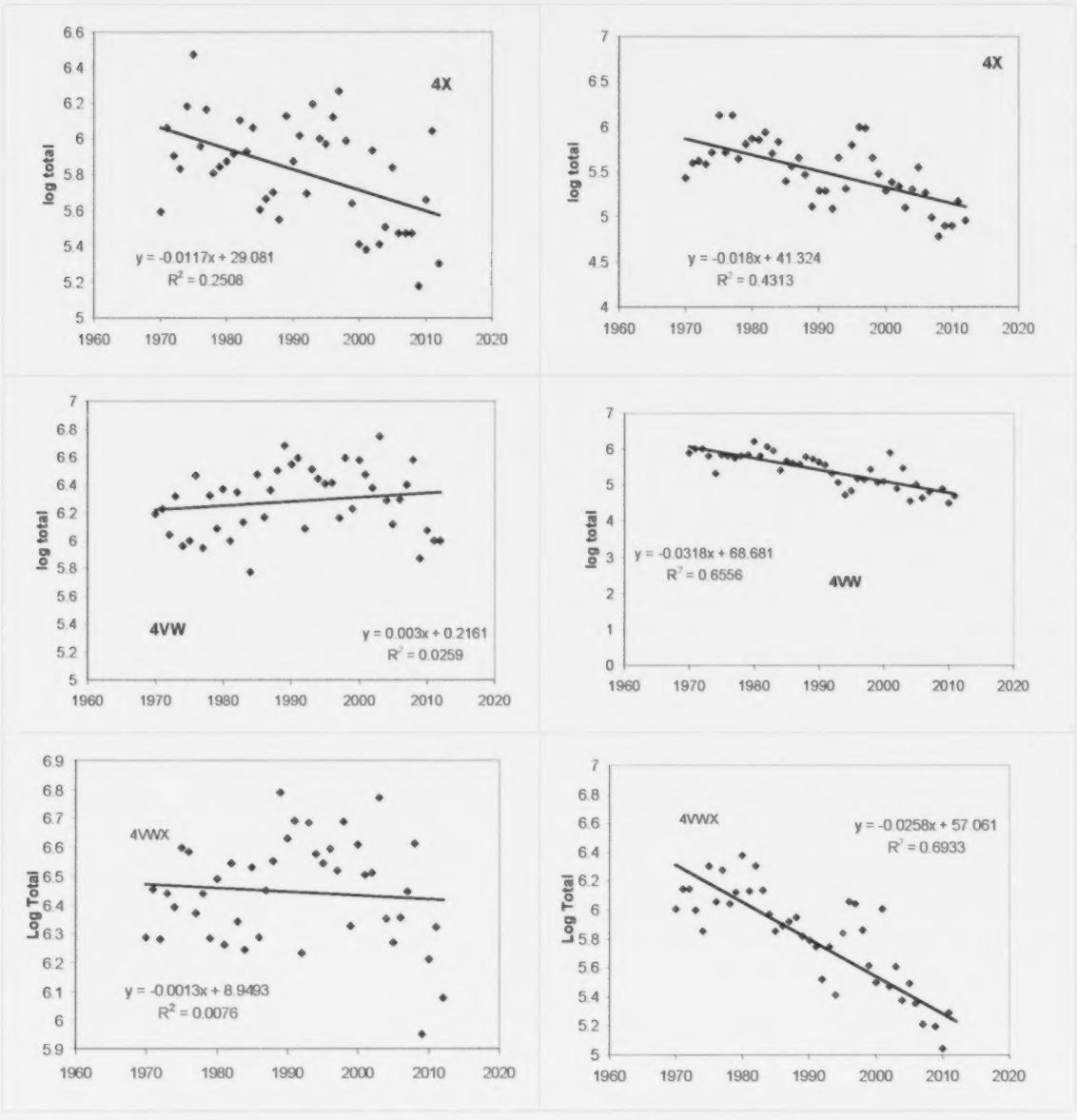


Figure 30. Log transformed catch rate (number per tow) of all length groups and mature length (>53 cm) groups of Atlantic Wolffish during the summer RV survey, 1970-2012, from Div. 4X, Div. 4VW, and Div. 4VWX.

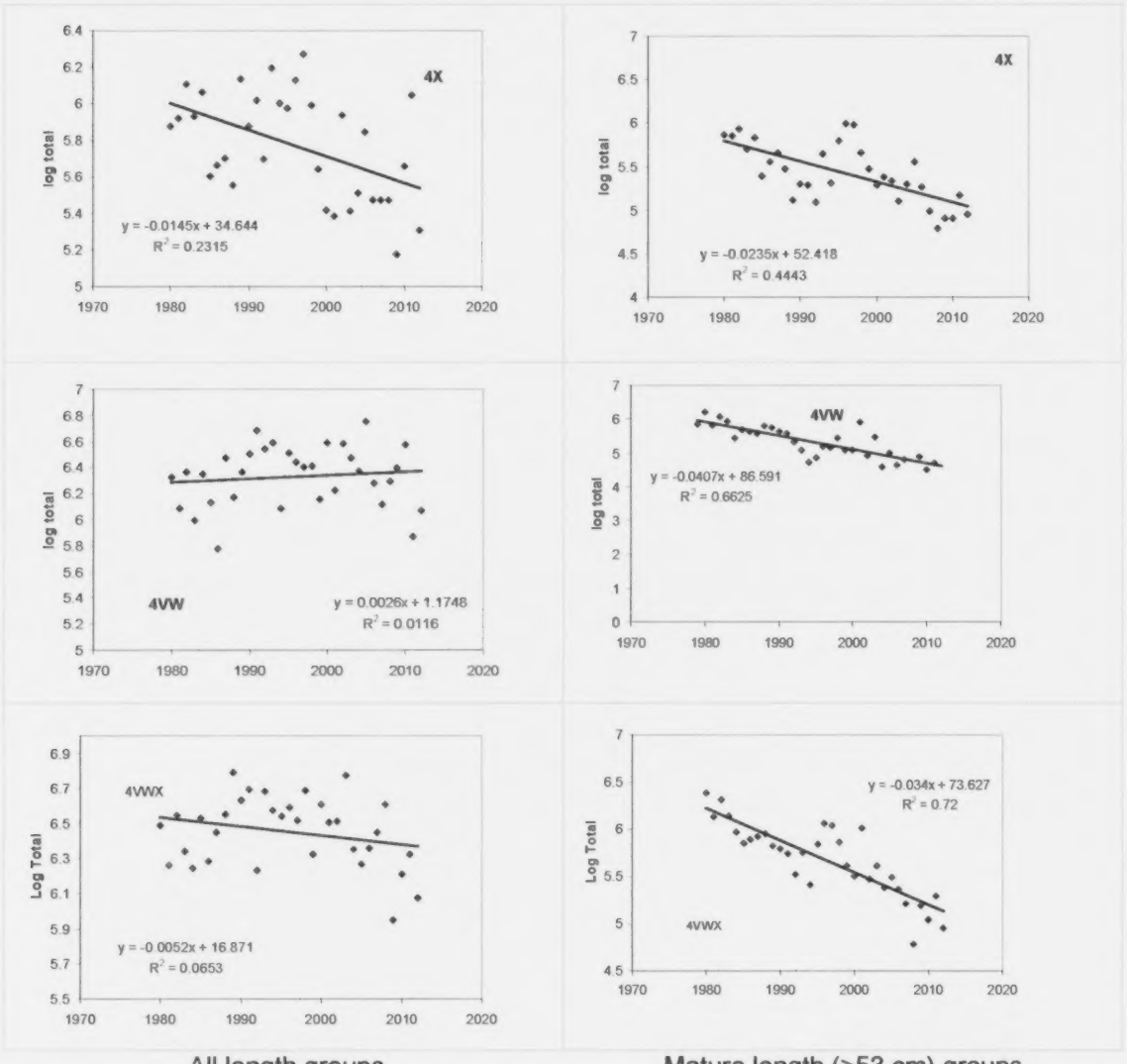


Figure 31. Log transformed catch rate (number per tow) of all length groups and mature length (>53 cm) groups of Atlantic Wolffish during the summer RV survey during a three generation period, 1980-2012 (33 years), from Div. 4X, Div. 4VW, and Div. 4VWX.

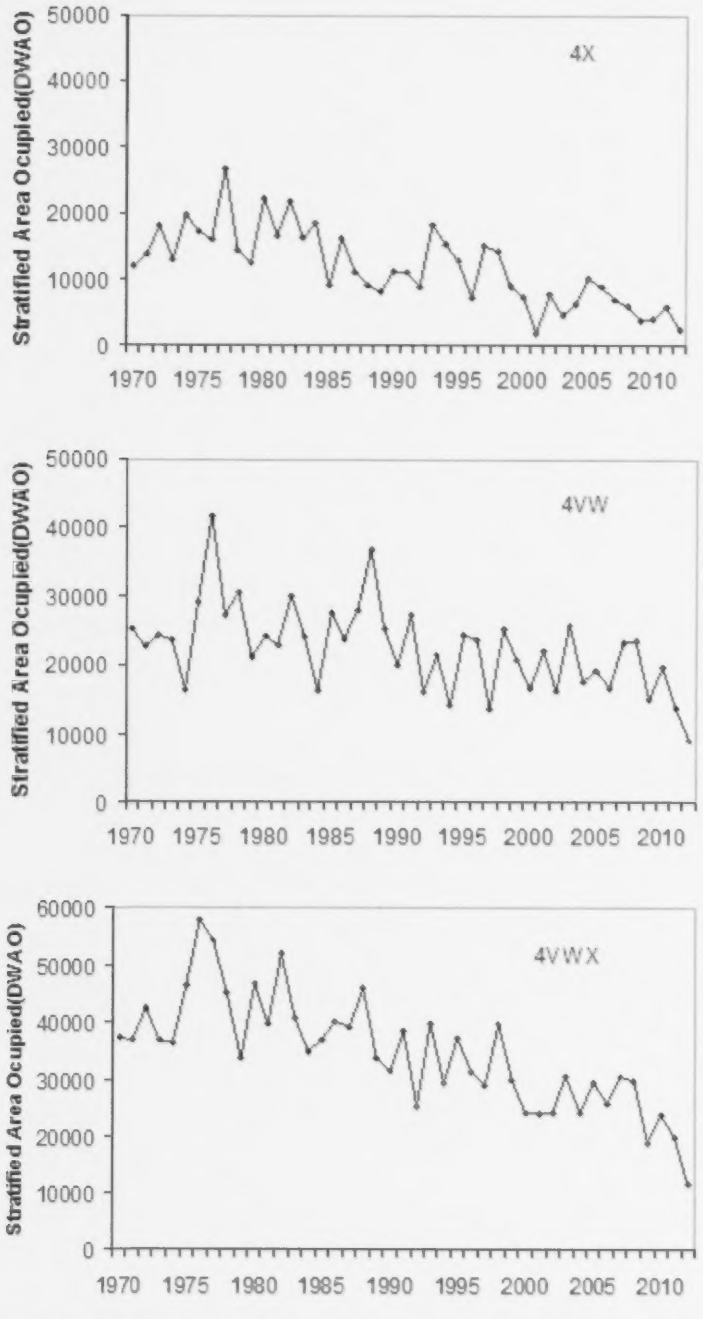


Figure 32. Design weighted area occupied (DWAO) of Atlantic Wolffish as indicated by the Summer RV Survey in Div. 4X, Div. 4VW and Div. 4VWX.

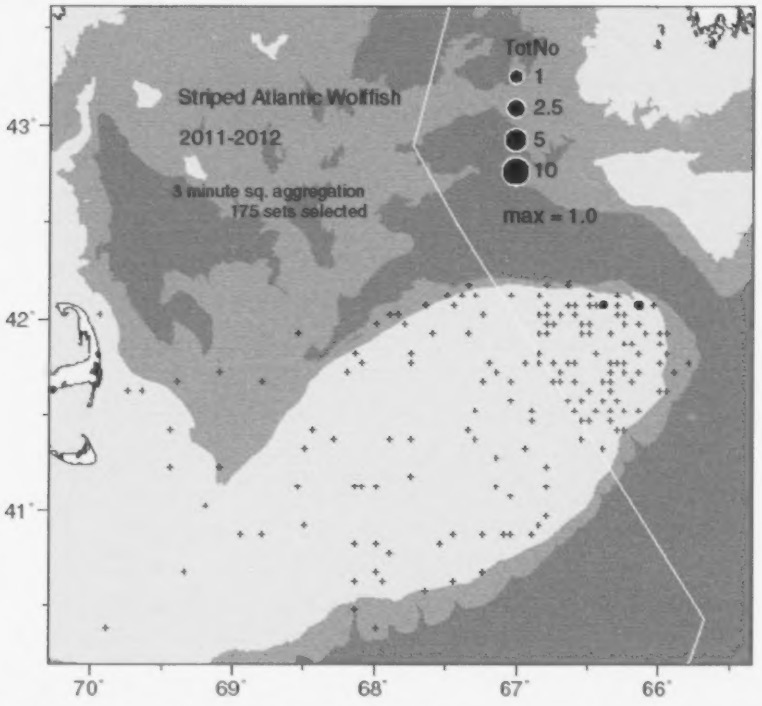


Figure 33. Distribution of Atlantic Wolffish, as indicated by the Georges Bank RV Survey, from 2011 to 2012.

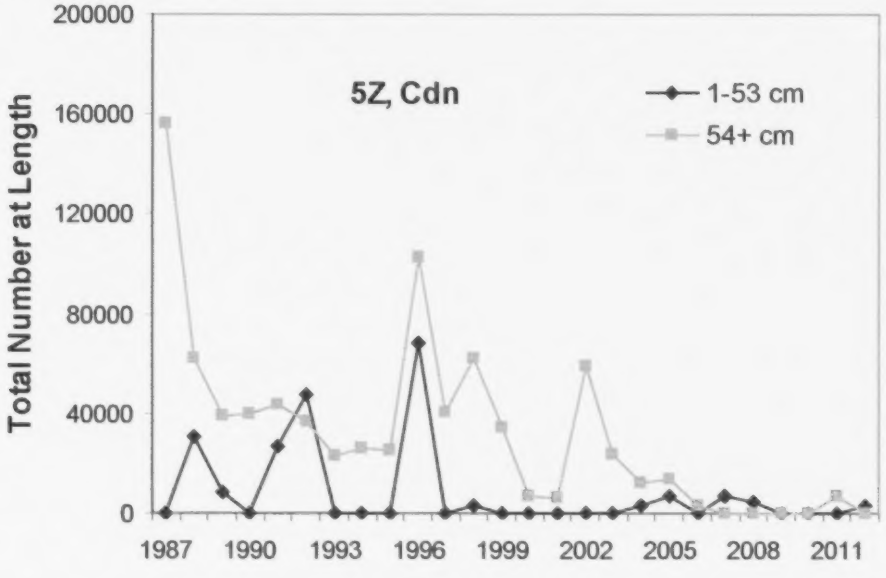


Figure 34. Abundance of immature (1-53 cm) and mature (>53 cm) Atlantic Wolffish from the Canadian strata of the Georges Bank RV survey in Div. 5Z.

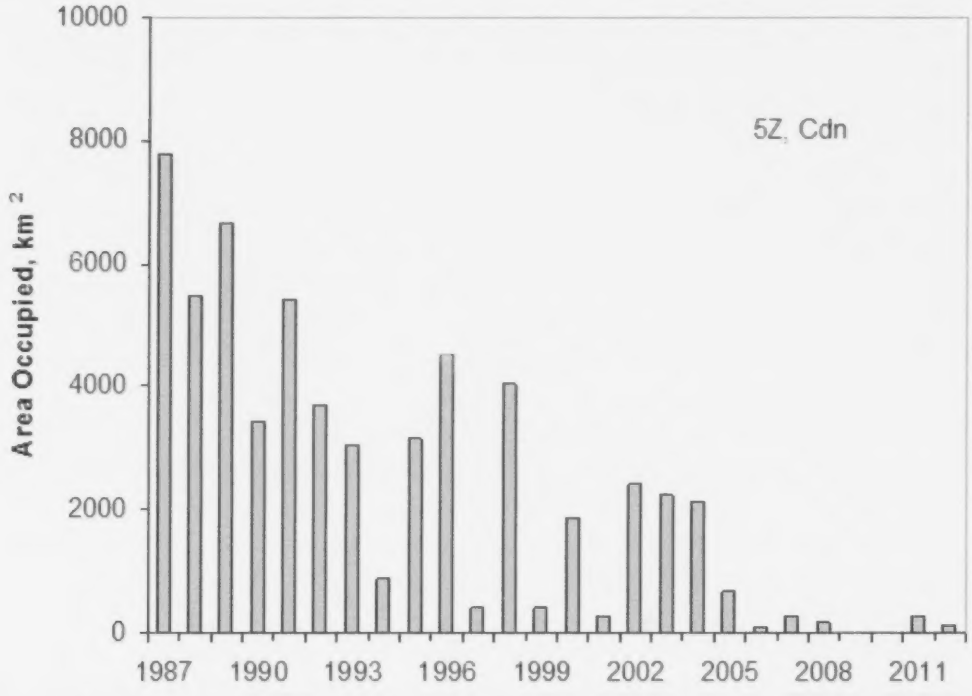


Figure 35. Design weighted area occupied (DWAO) of Atlantic Wolffish as indicated by the Georges Bank RV survey in Subdiv. 5Zc.

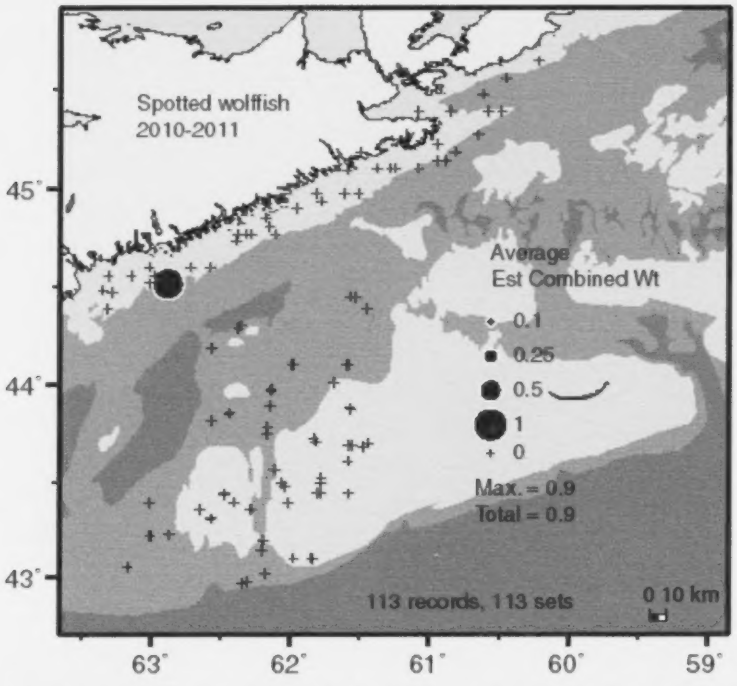


Figure 36. Distribution of Spotted Wolffish (kg/tow), as indicated by the 4VsW Sentinel Survey, in 2010 and 2011.

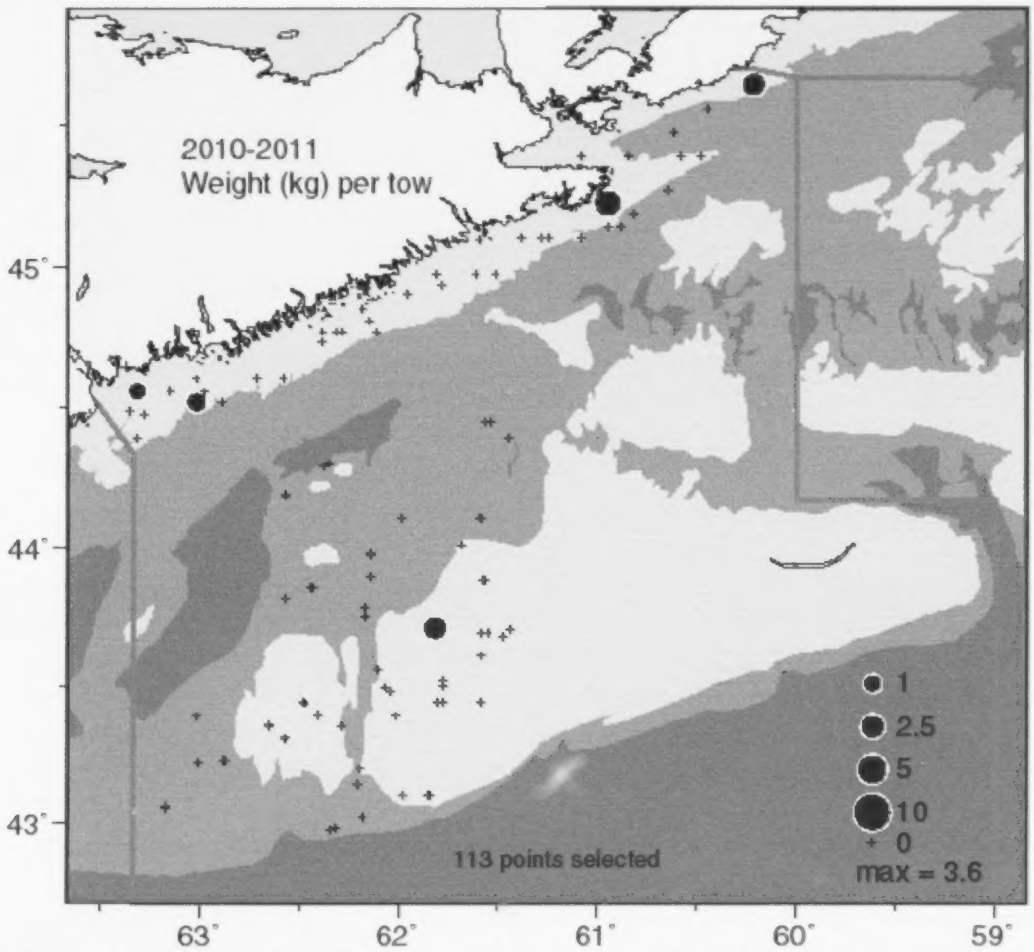


Figure 37. Distribution of Atlantic Wolffish as indicated by the 4VsW Sentinel Industry Longline Survey, 2010-11.

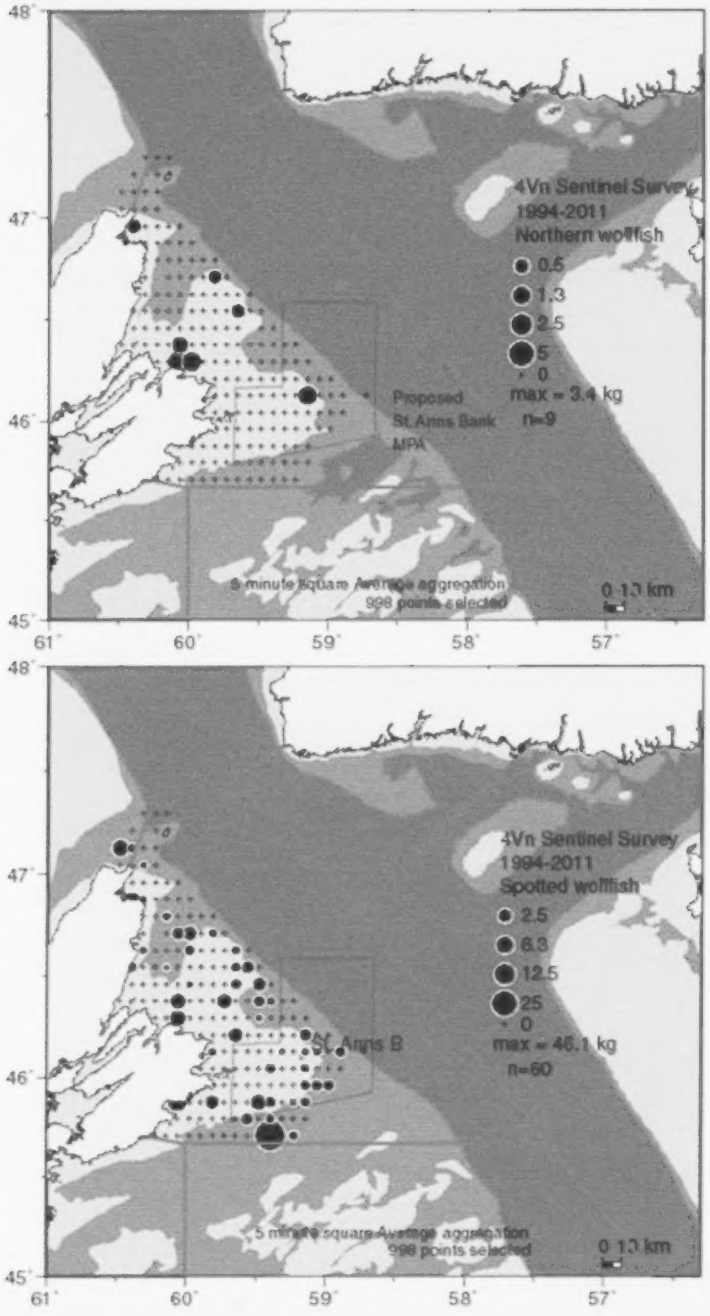


Figure 38. Distribution of Northern and Spotted Wolffish, as indicated by the 4Vn Sentinel Survey, 1994-2011.

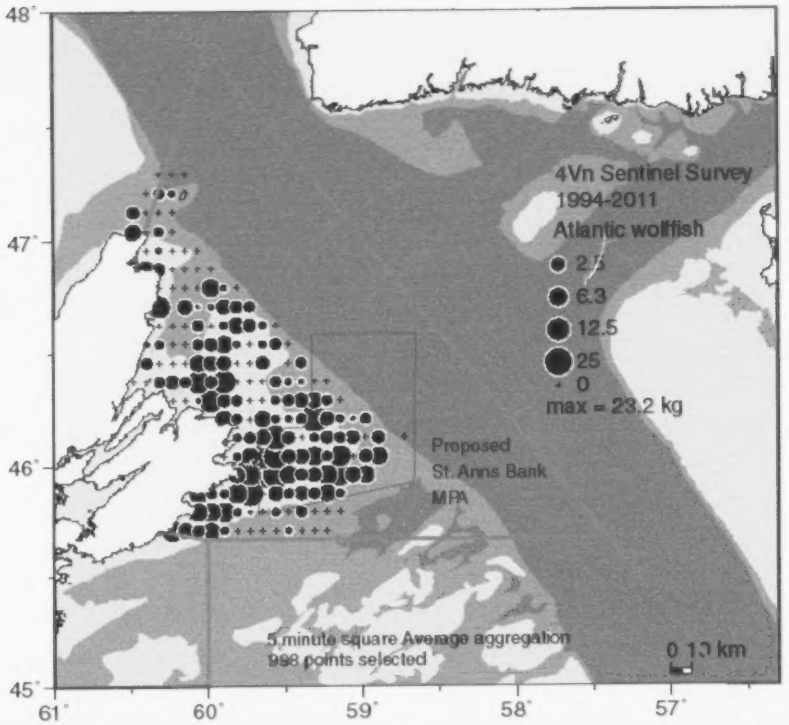


Figure 39. Numbers per tow (using 3 cm groupings) of Atlantic Wolffish from the 4Vn Sentinel Survey, 1996-2009.

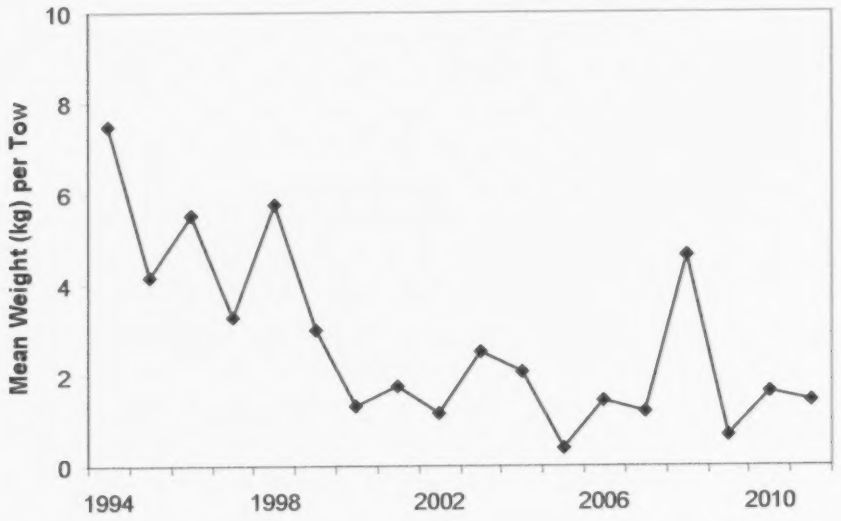


Figure 40. Mean catch rate (kg/tow) of Atlantic Wolffish from the fixed stations of 4Vn Sentinel Survey, 1994-2011.

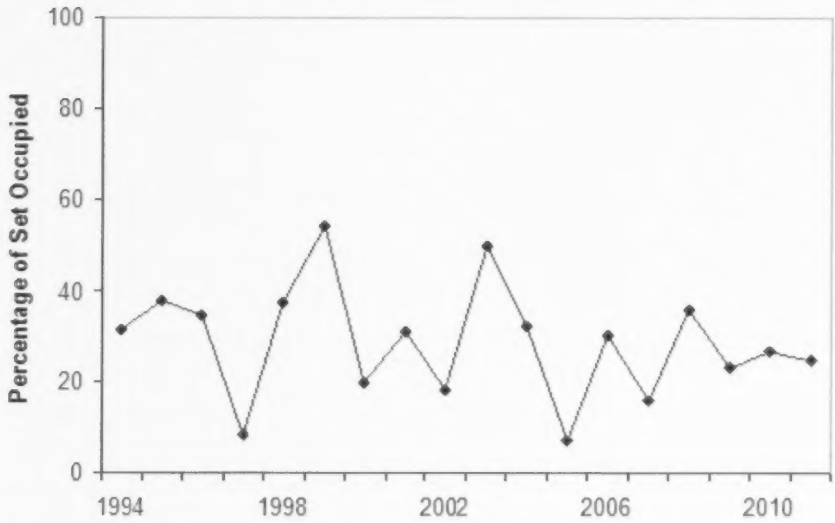


Figure 41. Percentage of sets occupied by Atlantic Wolffish during the 4Vn Sentinel Survey.

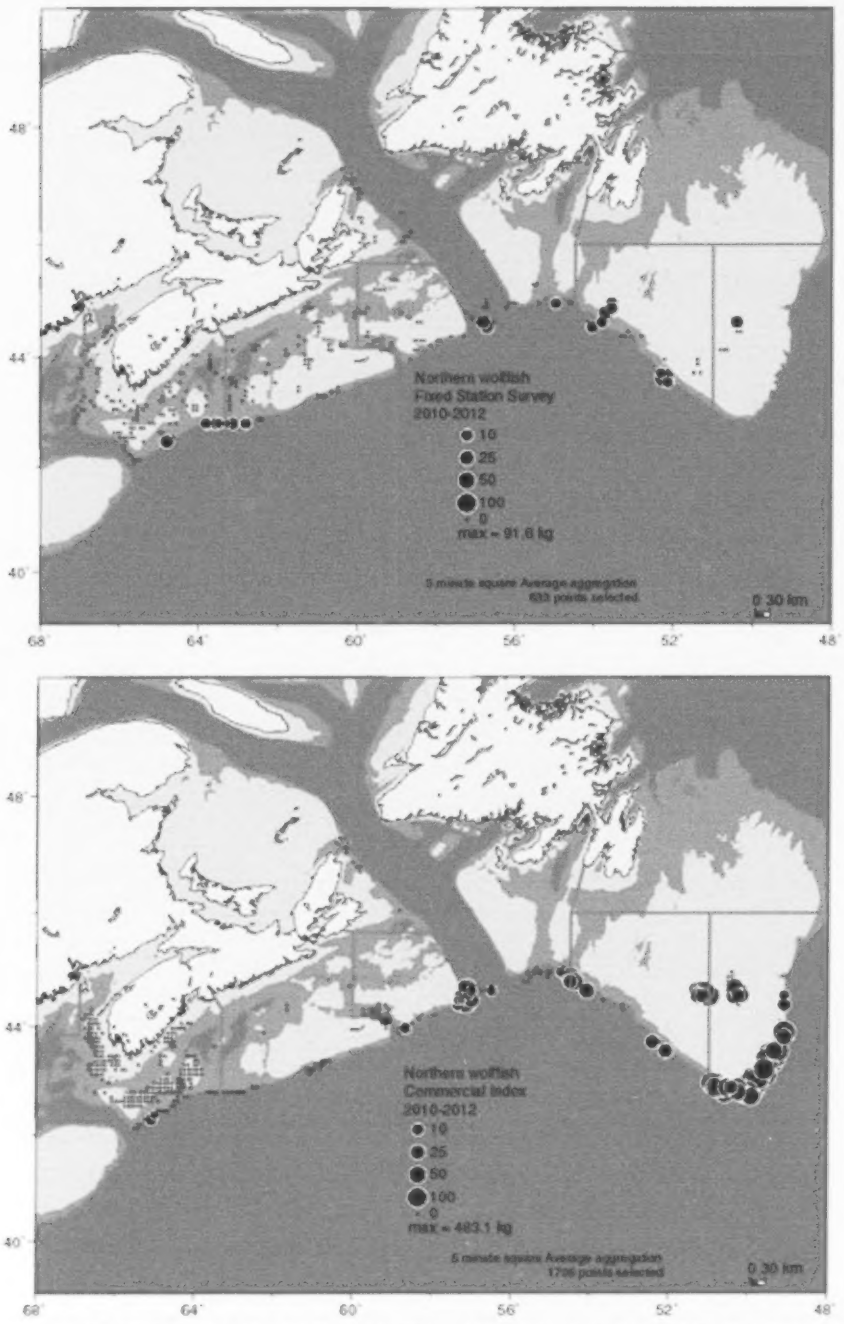


Figure 42. Distribution (kg/tow) of Northern Wolffish as indicated by the fixed station (upper panel) and commercial index station (lower panel) components of the Halibut Industry Longline Survey, 2010-12

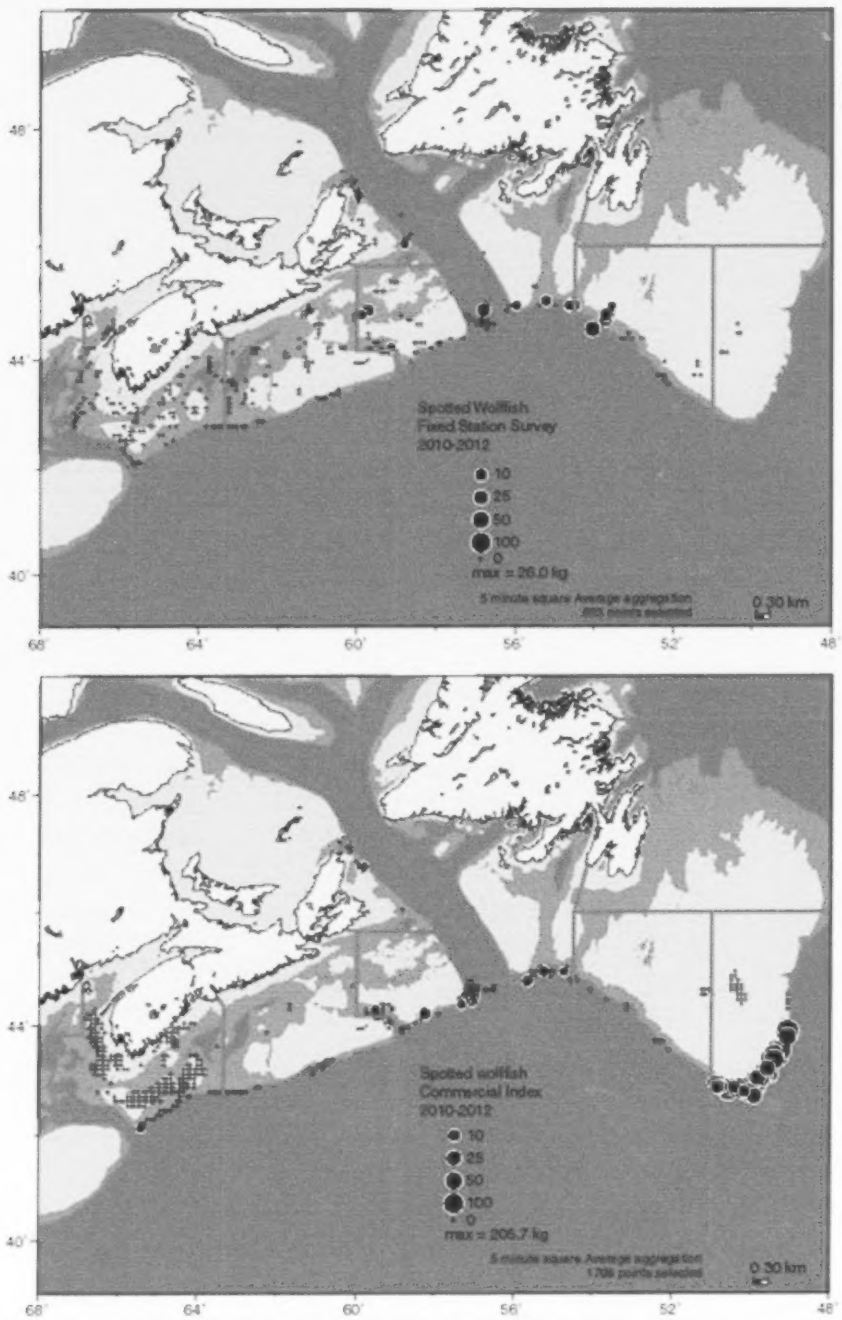


Figure 43. Distribution (kg/tow) of Spotted Wolffish as indicated by the fixed station (upper panel) and commercial index station (lower panel) components of the Halibut Industry Longline Survey, 2010-12.

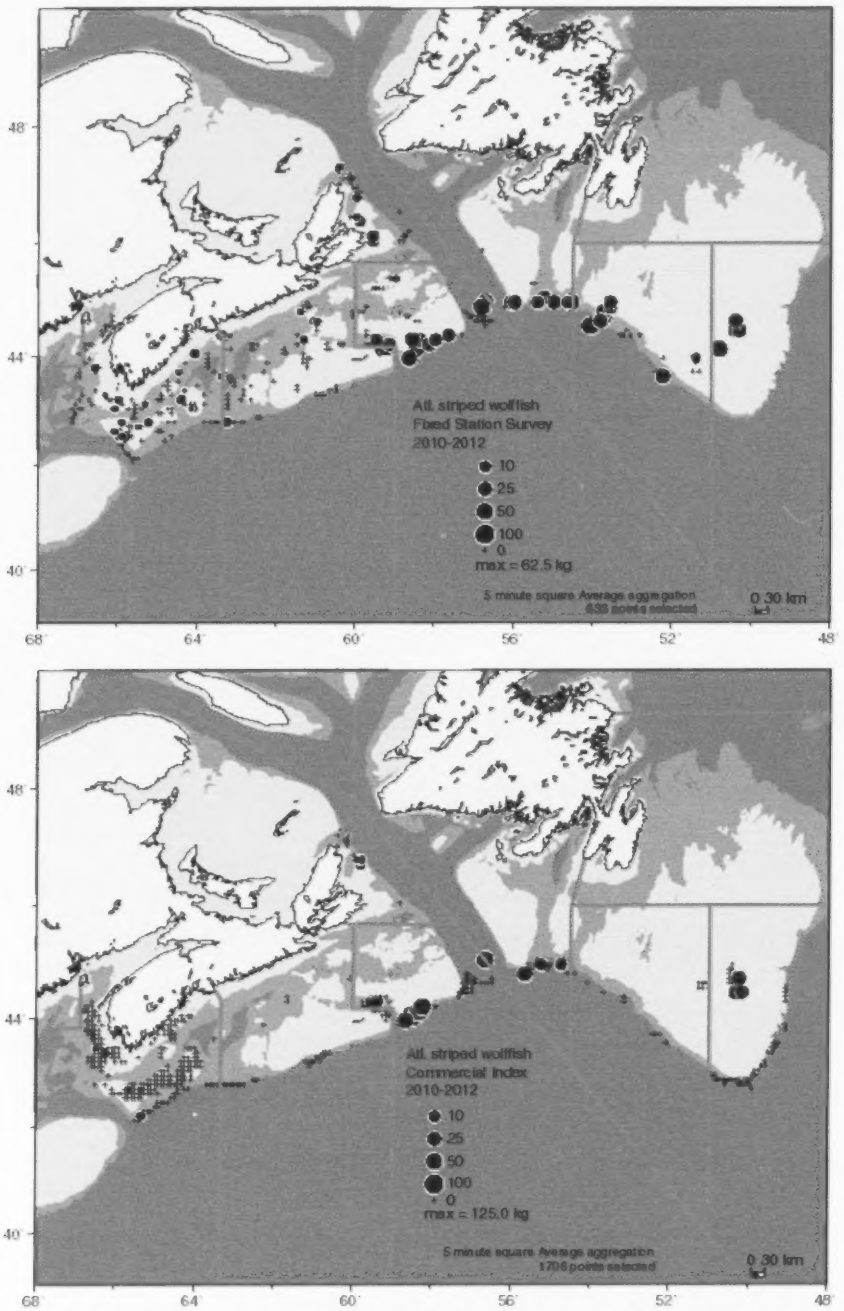


Figure 44. Distribution of Atlantic Wolffish as indicated by the fixed station (upper panel) and commercial index stations (lower panel) of the Halibut Industry Longline Survey, 2010-12.

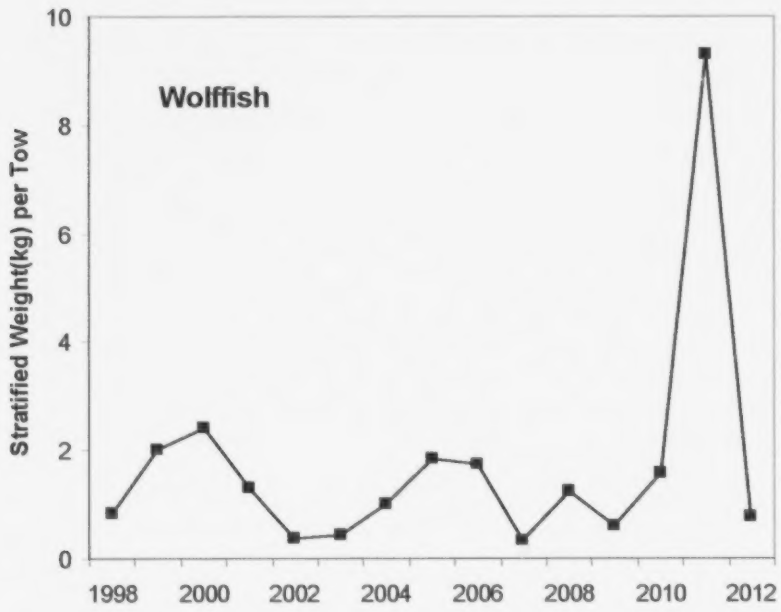


Figure 45. Stratified mean weight (kg) per tow of Atlantic Wolffish from all strata of the fixed station portion of the Halibut Industry Longline Survey, 1998-2012.

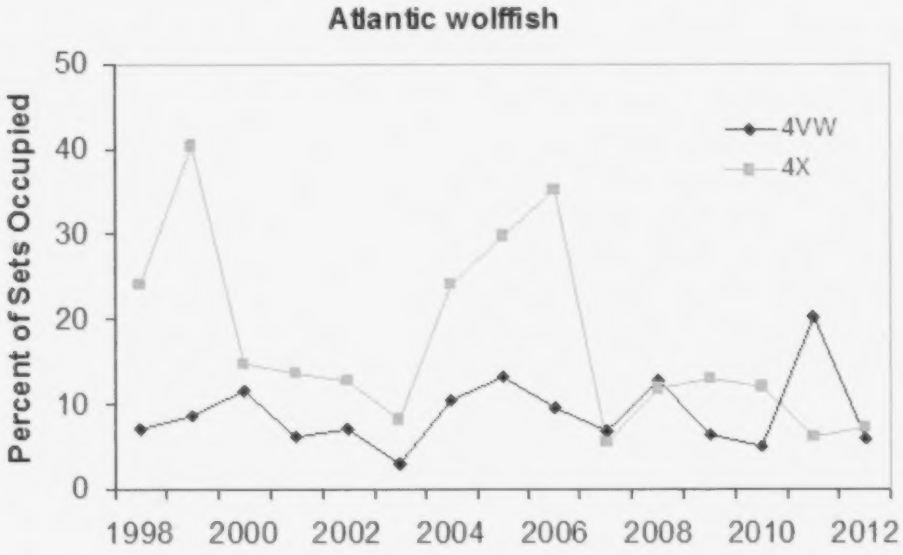


Figure 46. Percentage of sets containing Atlantic Wolffish in the fixed station portion of the Halibut Industry Longline Survey.

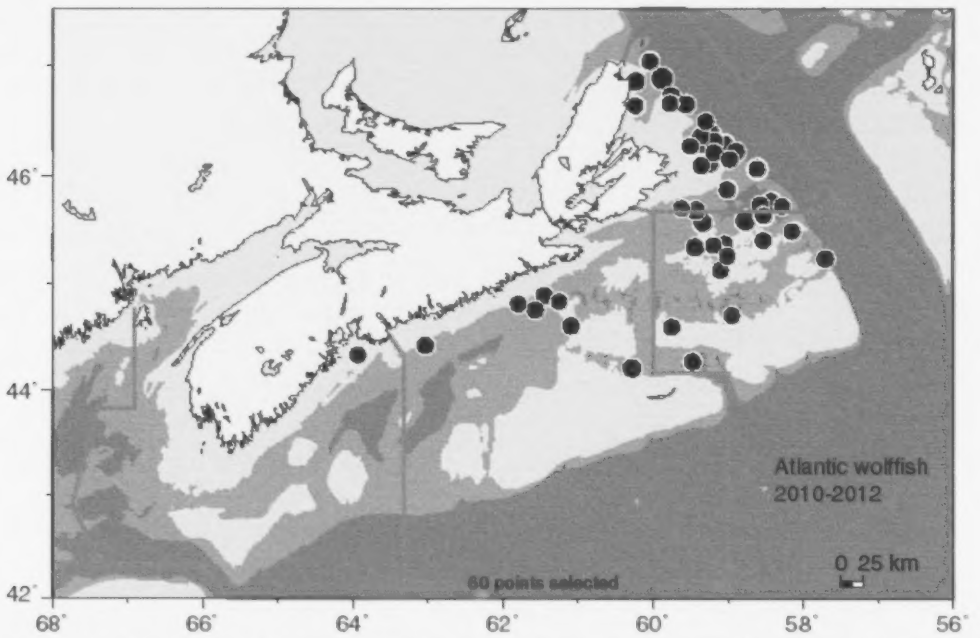


Figure 47. Distribution of Atlantic Wolffish, as indicated by the Snow Crab Industry Survey, 2010-12.

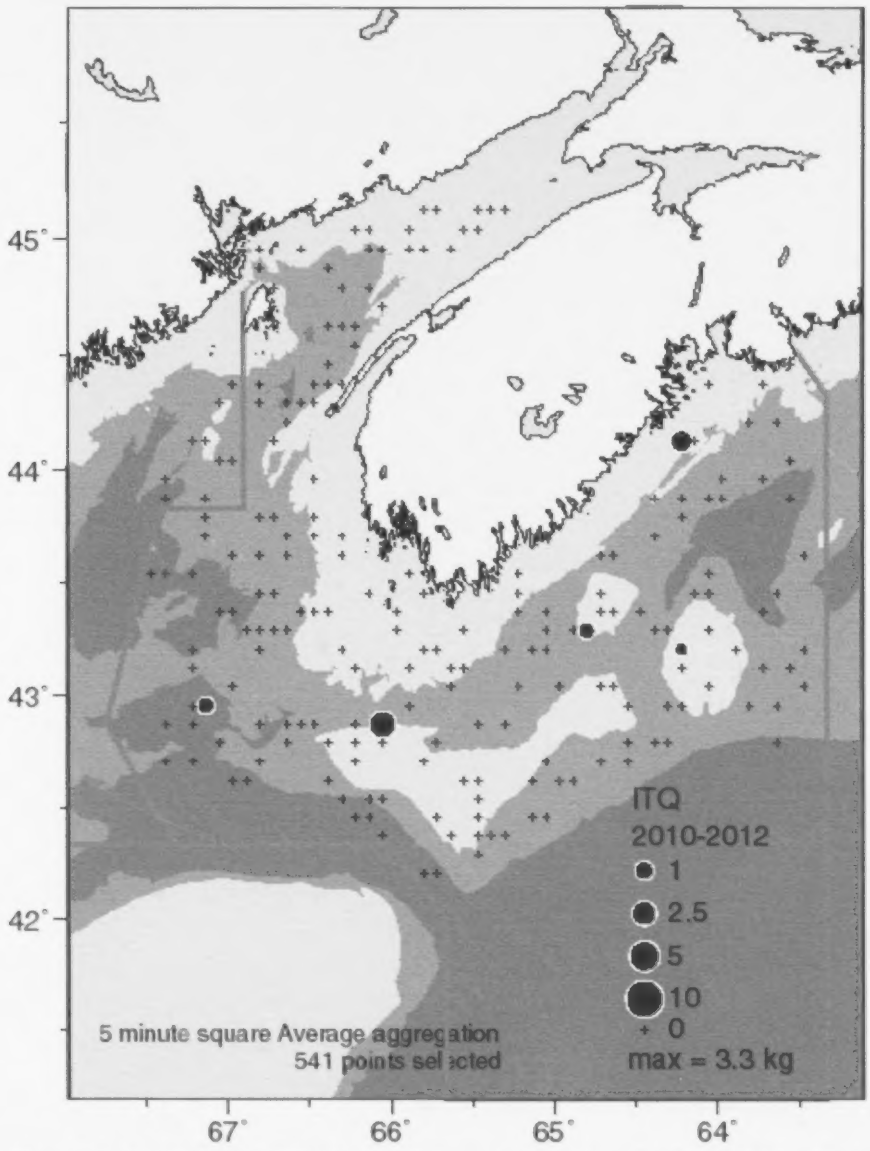


Figure 48. Distribution of Atlantic Wolffish, as indicated by the ITQ Industry Survey, 2010-12.

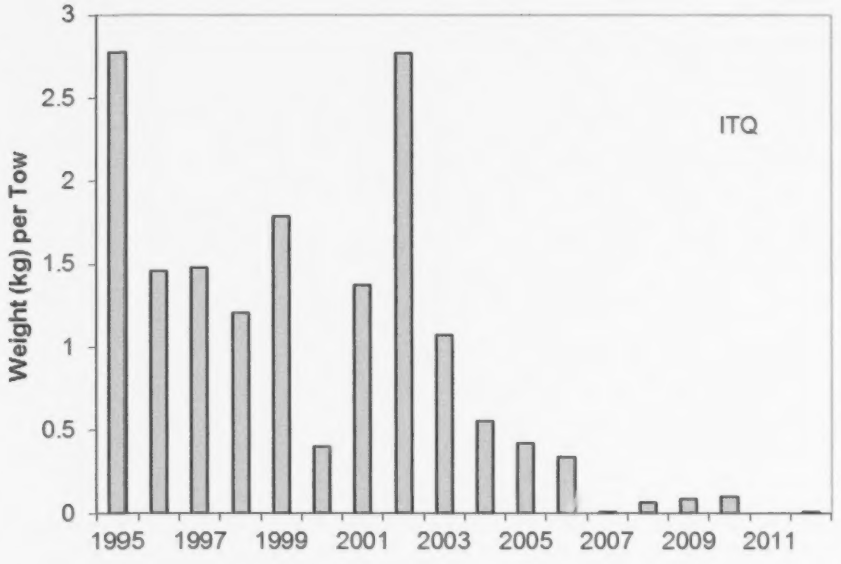


Figure 49. Abundance (kg/tow) of Atlantic Wolffish, as indicated by the ITQ Industry Survey, 1995-2012.

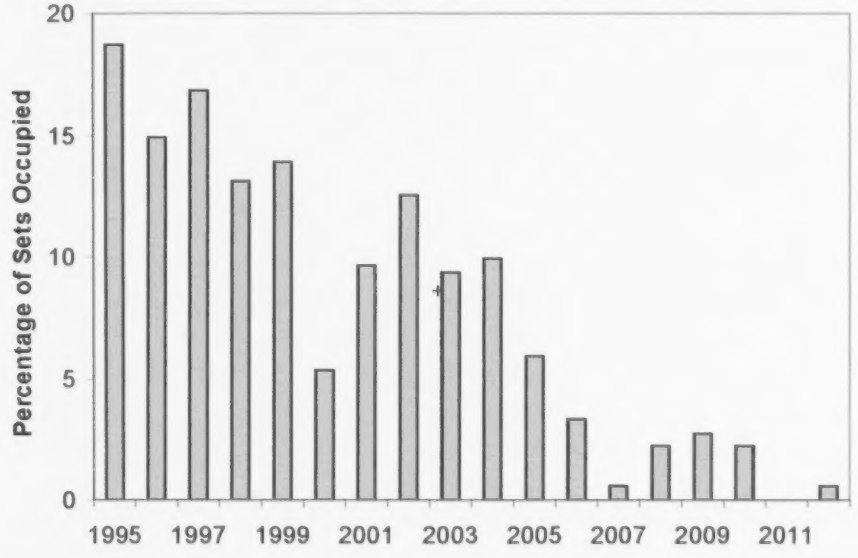


Figure 50. Percentage of sets containing Atlantic Wolffish in the ITQ Industry Survey in Div. 4X.

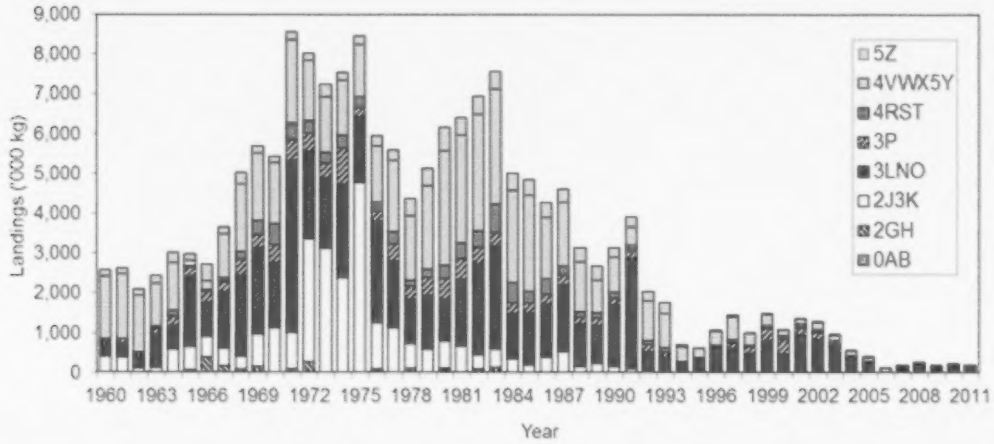


Figure 51. Reported landings of unspeciated wolffish in 1960-2011 from NAFO, ZIF, and MARFIS databases. Data do not include discards at sea.

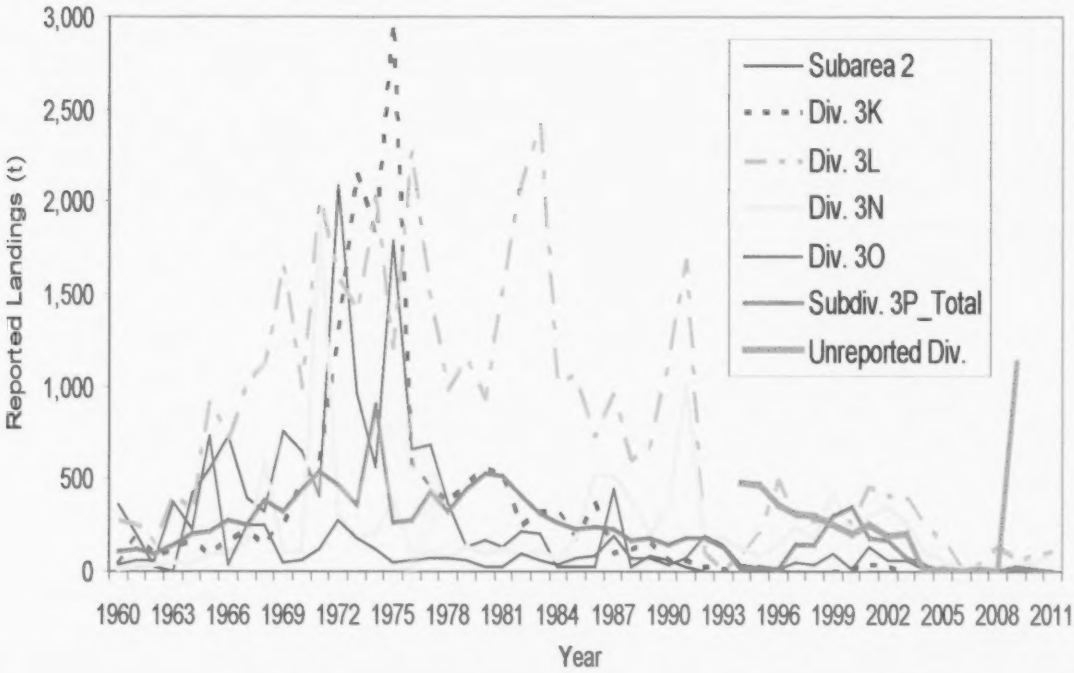


Figure 52. NAFO-reported landings of wolffish (unspeciated; in tonnes) by Canada and other countries in NAFO Subareas 2, and 3 from 1960 to 2011. Data do not include discards at sea. Note that Subarea 1 and parts of Subarea 2 are outside Canadian waters.

Figure 53. Canadian commercial landings of wolffish, in t, from NAFO and DFO databases, for Div. 4VW, Div. 4X5Y, and Div. 5Z, from 1963 to 2012.

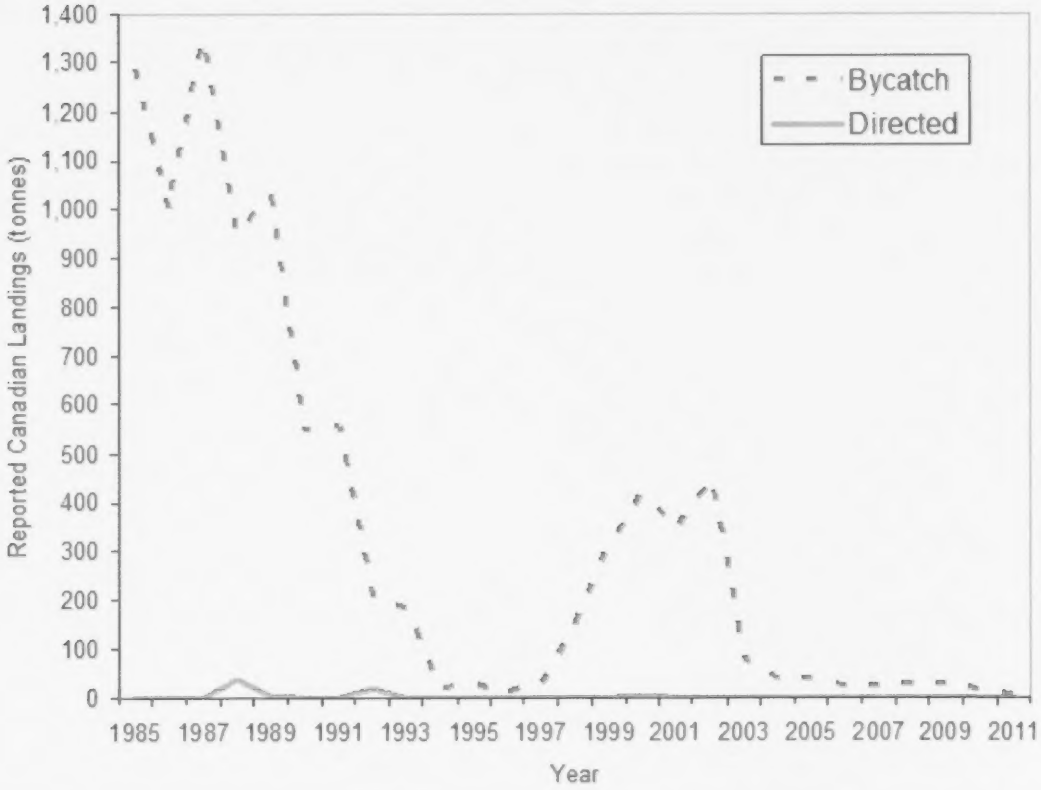


Figure 54. DFO ZIF-reported directed and bycatch wolffish landings (unspeciated; in tonnes) in Canada's EEZ of NAFO Div. 2GHJ3KLNOP in 1985-2011. Data do not include discards at sea.

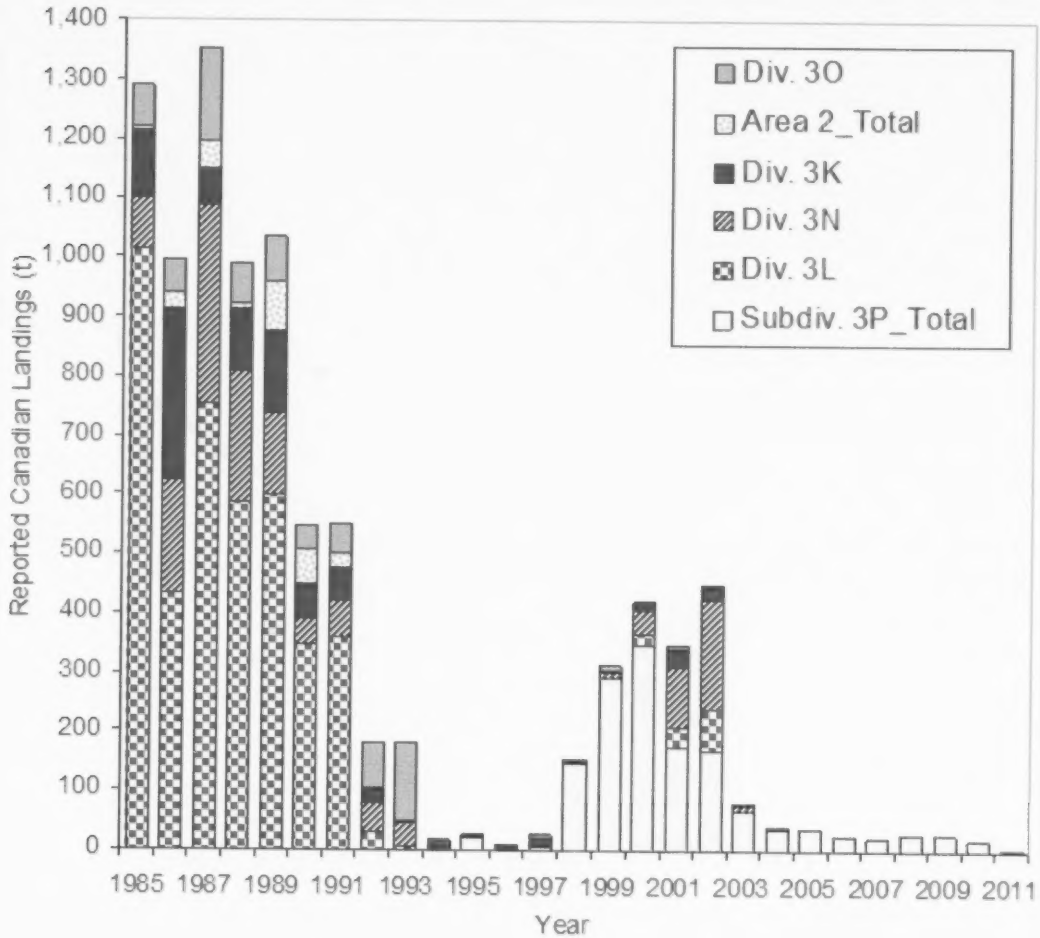


Figure 55. DFO ZIF-reported wolffish landings (unspeciated; in tonnes) in Canada's EEZ of NAFO Subarea 2 and Div. 3KLNOP in 1985-2011. Data do not include discards at sea.

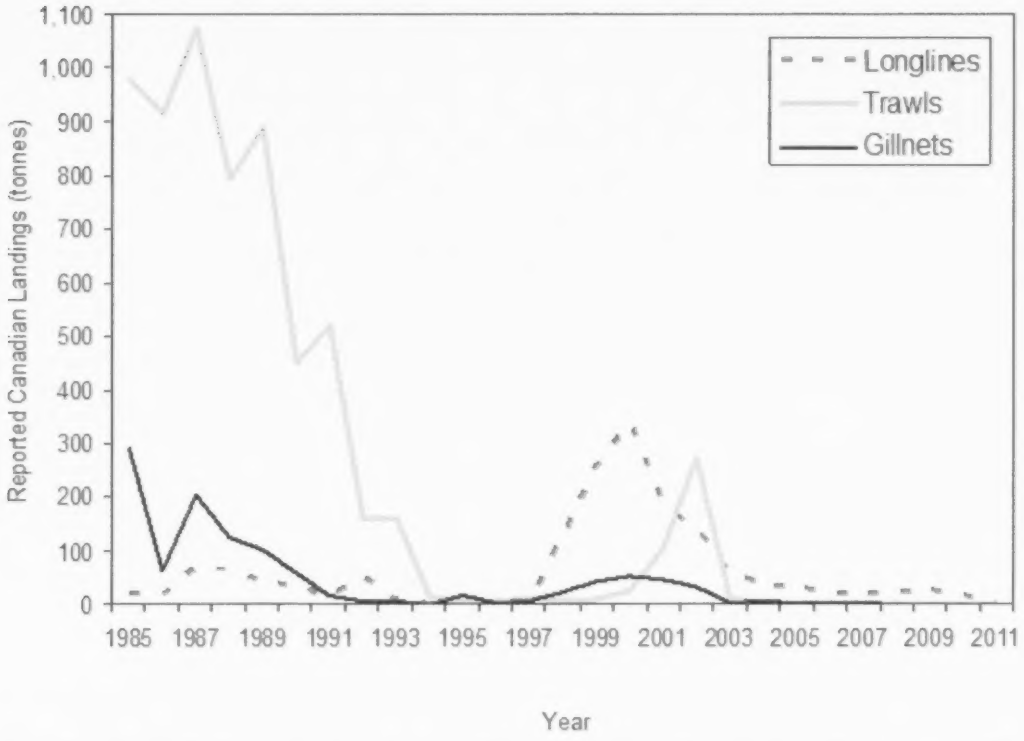


Figure 56. DFO ZIF-reported wolffish landings (unspeciated; in tonnes) by gear type in Canada's EEZ of NAFO Div. 2GHJ3KLNOP in 1985-2011. Data do not include discards at sea.

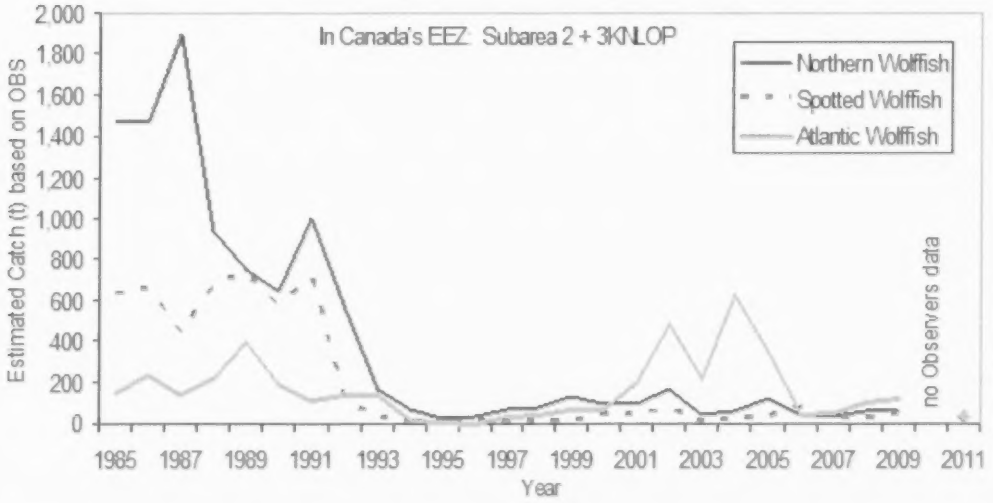


Figure 57. Speciated wolffish at-sea catch estimates (in tonnes) from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Div. 3KLNOP in 1985-2011. Data are from Canadian Fisheries Observers and include discards at sea.

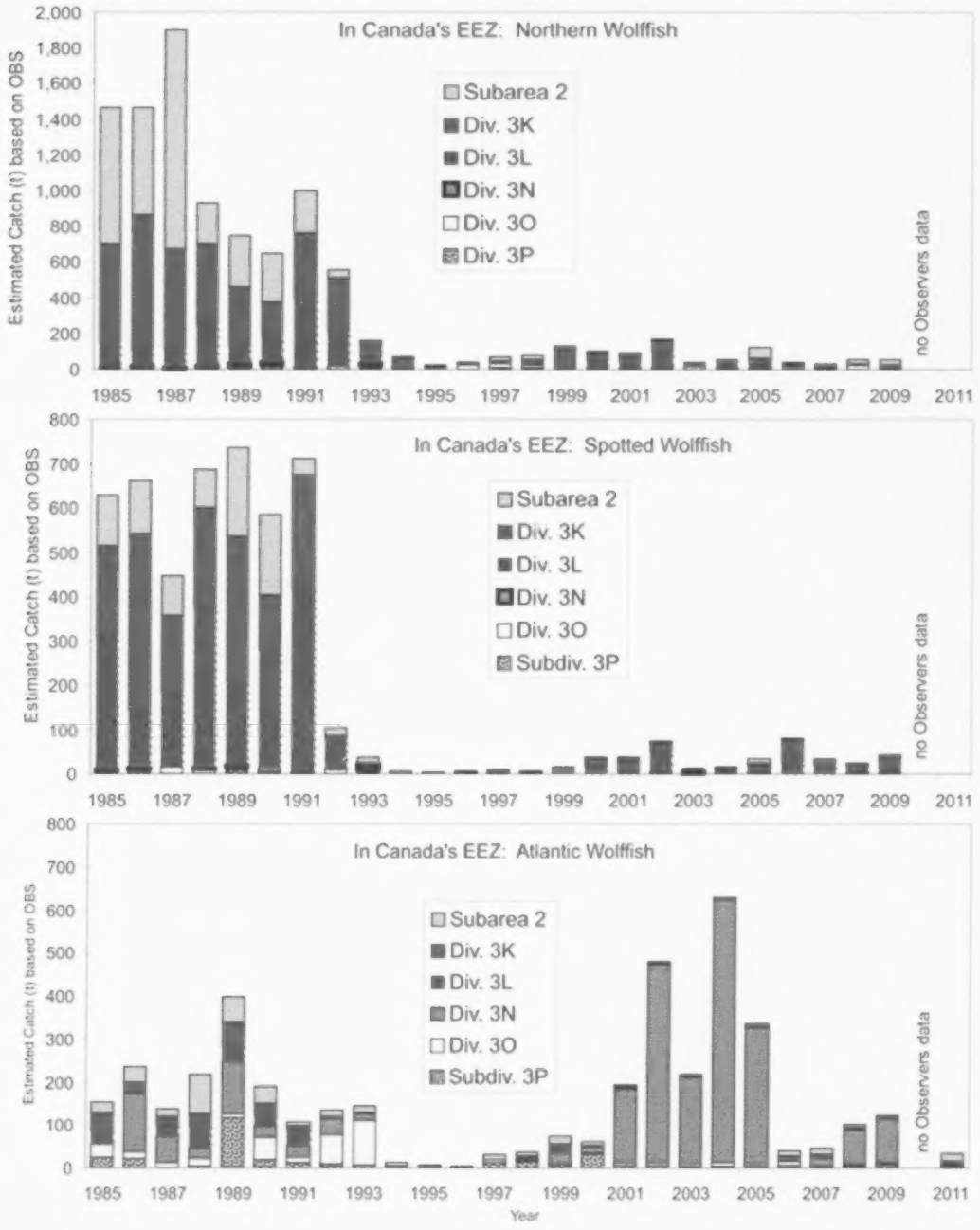


Figure 58. Speciated wolffish at-sea catch estimates (in tonnes) by Subarea/Division from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Div. 3KLNOP in 1985-2011. Data are from Canadian Fisheries Observers and include discards at sea. Scale of Y-axis is different for Northern Wolffish graph.

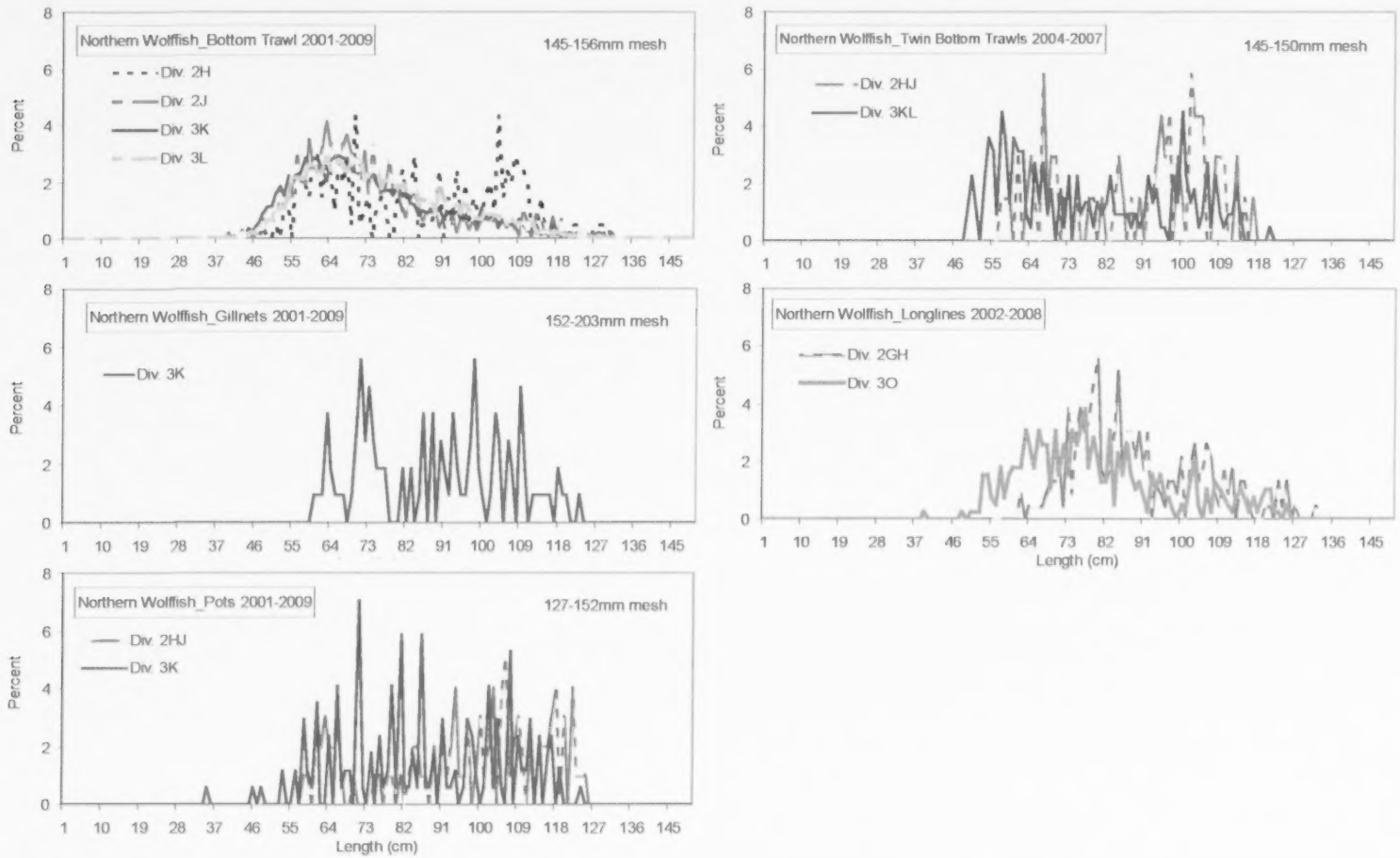


Figure 59. Length frequency data for Northern Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subareas 2, and 3 in 2001-09. Data are from Canadian Fisheries Observers.

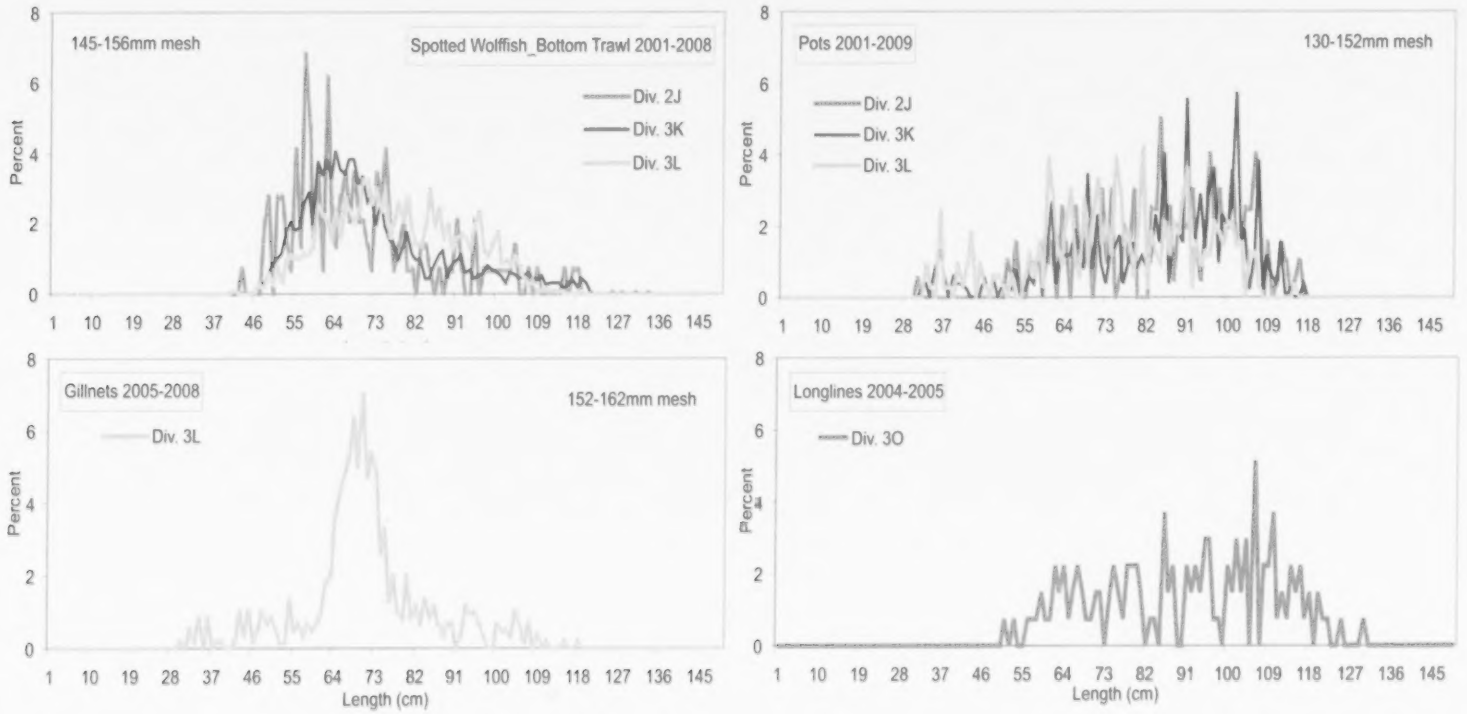


Figure 60. Length frequency data for Spotted Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subareas 2, and 3 in 2001-09. Data are from Canadian Fisheries Observers.

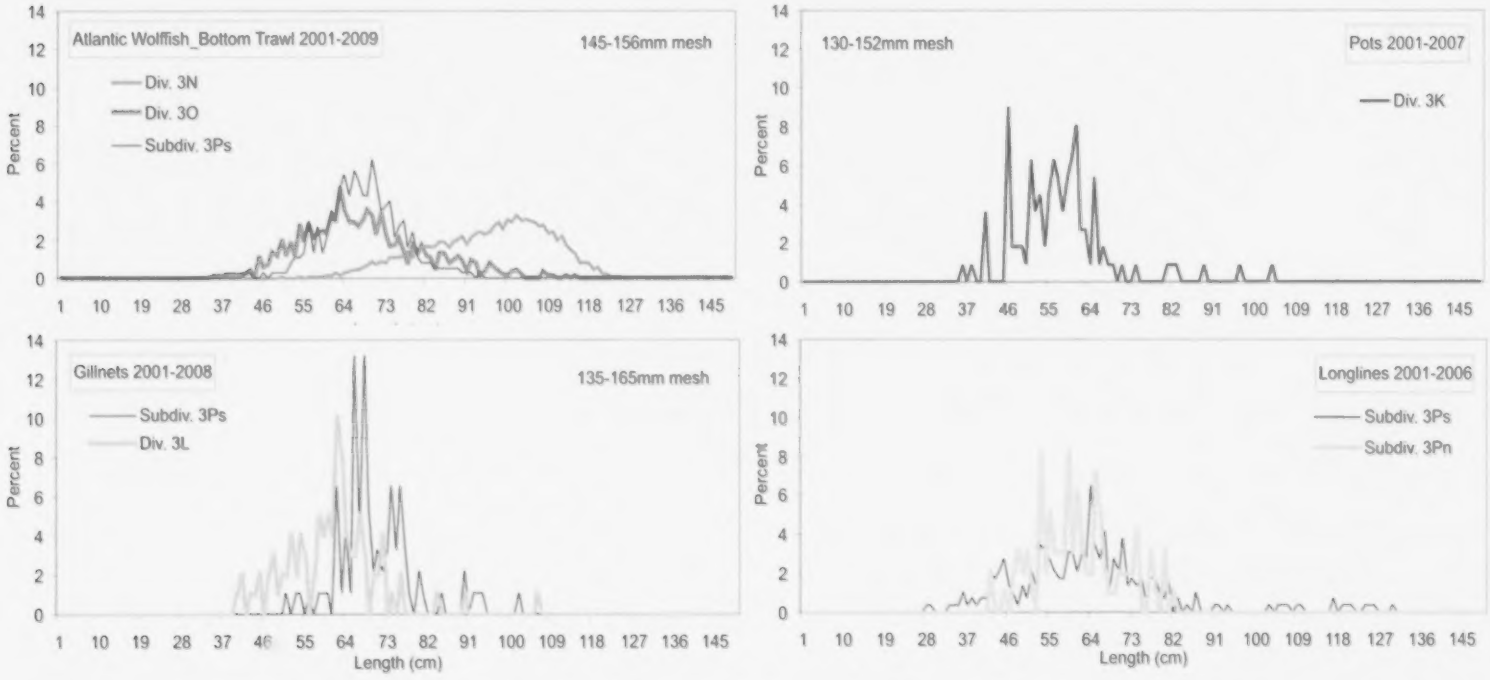


Figure 61. Length frequency data for Atlantic Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subarea 3 in 2001-09. Data are from Canadian Fisheries Observers.

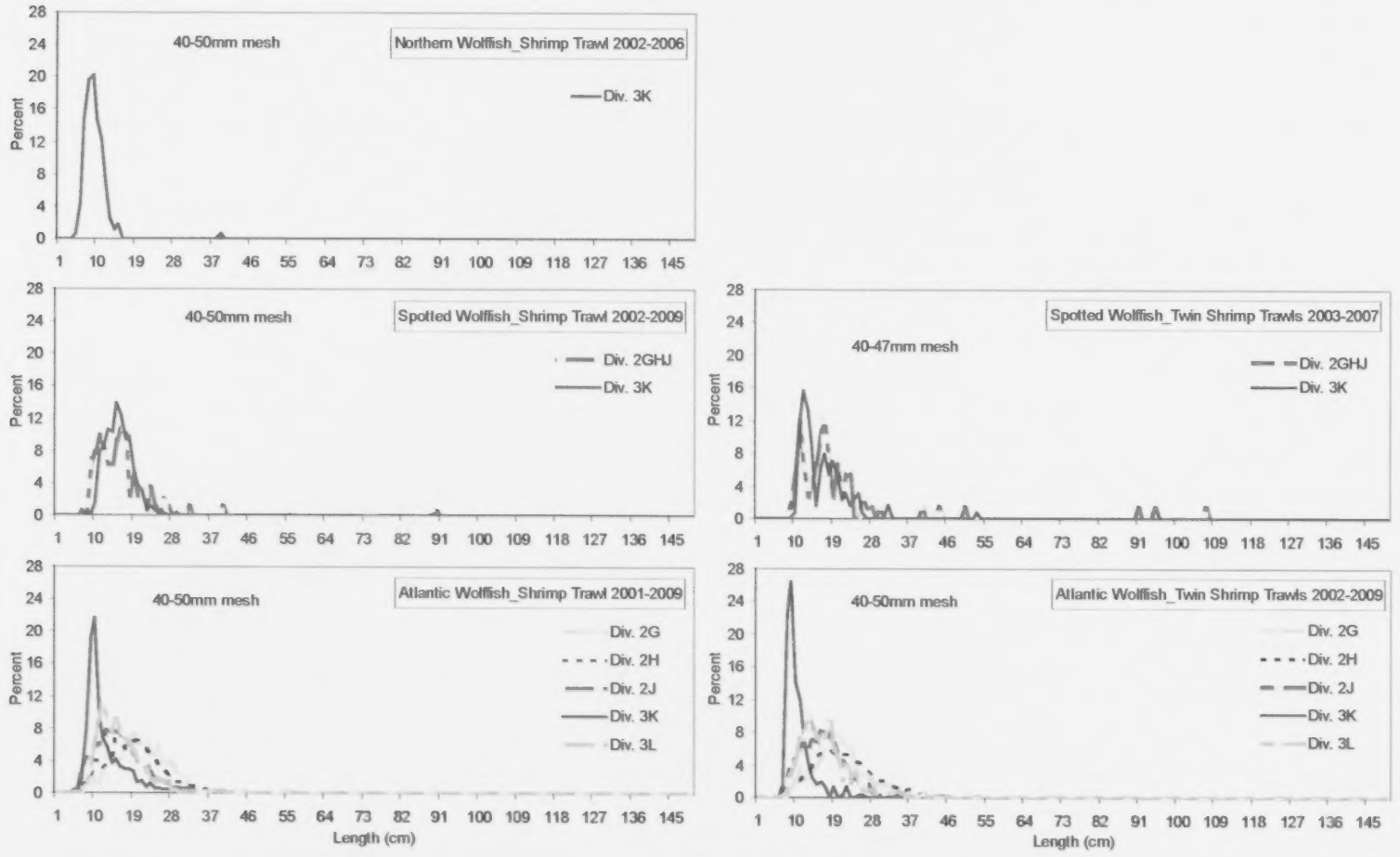


Figure 62. Length frequency data for three species of wolffish caught by commercial shrimp trawls in Canada's EEZ of NAFO Subareas 2 and 3 in 2001-09. Data are from Canadian Fisheries Observers.

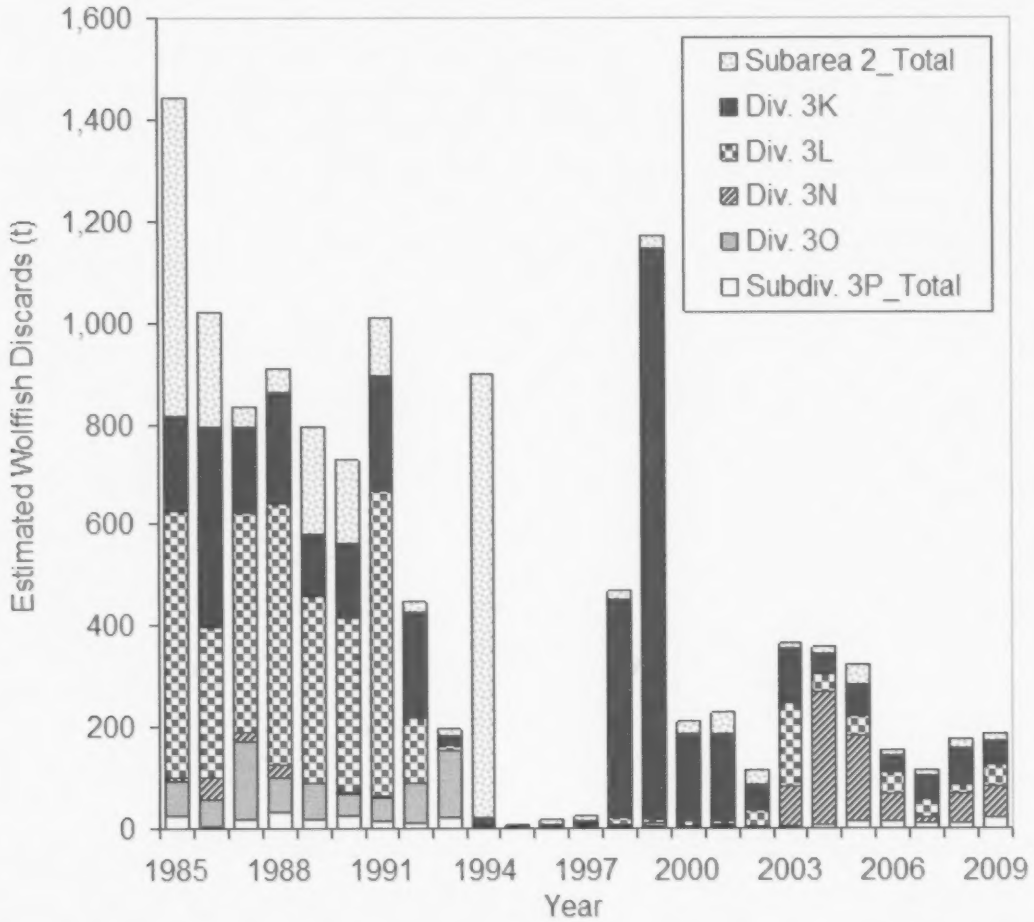


Figure 63. Wolffish at-sea discard estimates (in tonnes) from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Div. 3KLNOP in 1985-2009. Data are from Canadian Fisheries Observers.

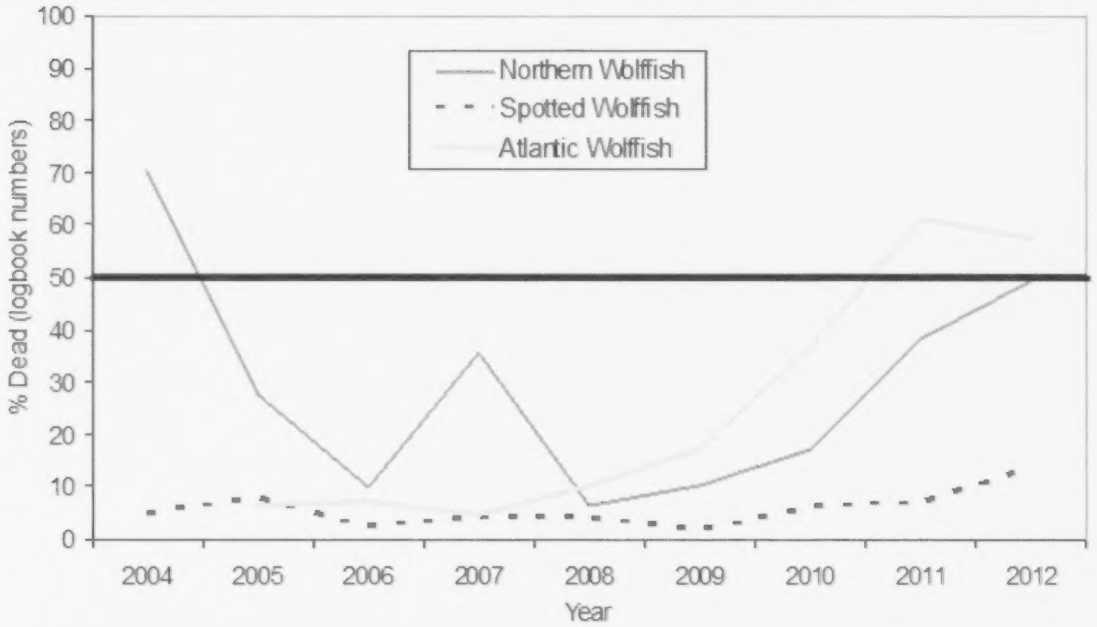


Figure 64. Percentage of wolffish (numbers) released dead at-sea in various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Div. 3KLNOP in 2004-2012. Data were recorded by fishers in SARA logbooks, as of 14 December 2012.

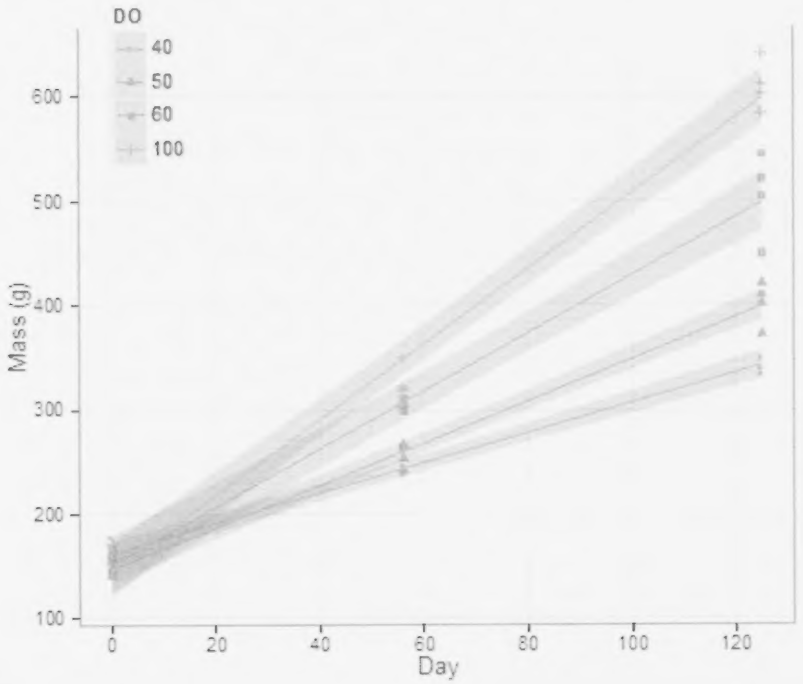


Figure 65. Change in mass of juvenile Spotted Wolffish exposed to 4 different DO treatments. There were 4 replicate tanks (except 3 at 30% sat.) of approximately 22 fish for each treatment. Linear fits with 95% confidence bands are shown. (D. Chabot, Maurice-Lamontagne Institute, unpublished data)

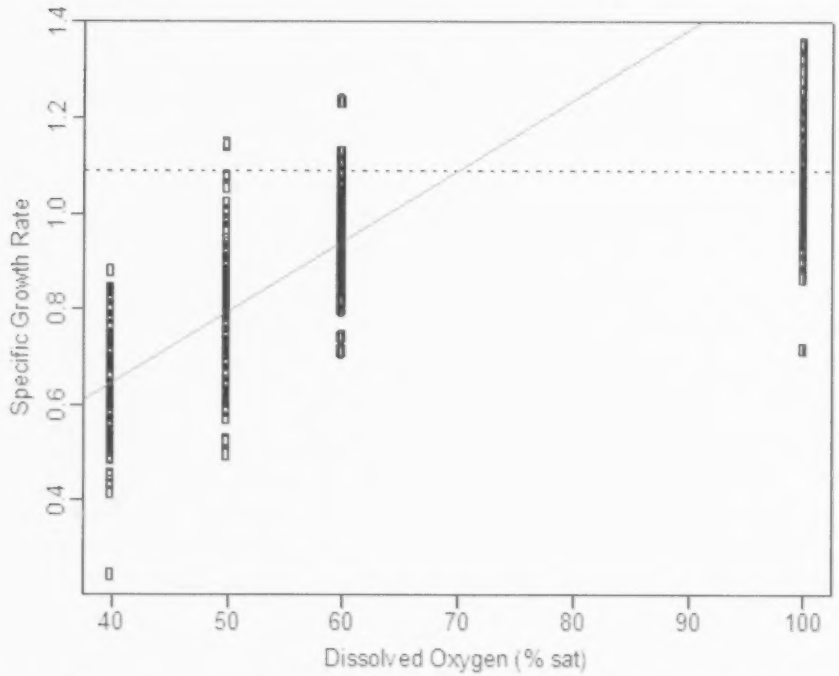


Figure 66. Specific growth rate of juvenile Spotted Wolffish exposed to 4 different DO treatments. (D. Chabot, Institut Maurice-Lamontagne, unpublished data). Dashed line is the average growth rate in normoxia. The solid line shows the relationship between growth rate and dissolved oxygen. These data suggest that growth rate becomes dependent upon dissolved oxygen below 70% sat.